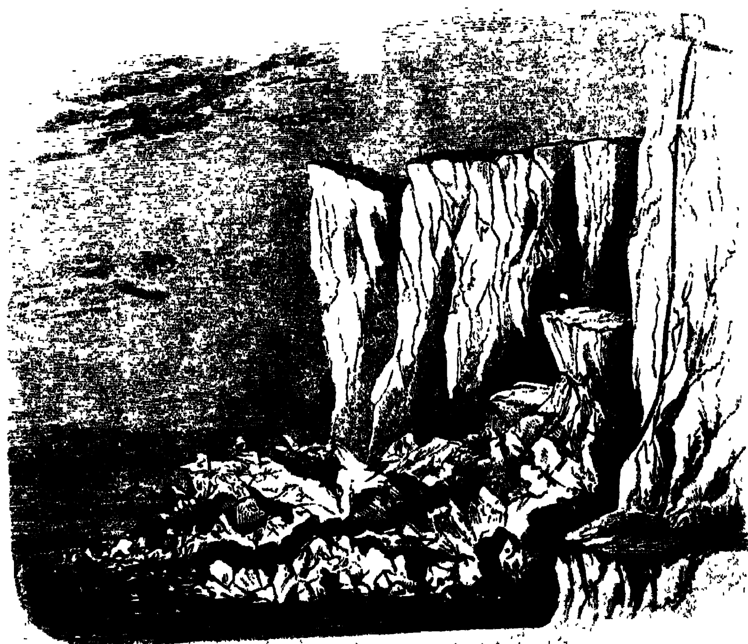


ELECTRICITY.—(See Page [illegible].)



GALVANISM.—(See Page 311.)

A MANUAL OF ELECTRICITY

INCLUDING

GALVANISM, MAGNETISM, DIAMAGNETISM, ELECTRO-DYNAMICS, MAGNETO-ELECTRICITY, AND THE ELECTRIC TELEGRAPH.

BY

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PREFACE.

The favourable manner in which the former editions of the Author's "Lectures on Electricity" have been received by the public (the third Edition having long been out of print); and the repeated demands on the publishers for copies, which they have been unable to supply, have induced him to bestow some care and labour on the preparation of the work, the first part of which is now presented to the public. The sciences of Electricity and Magnetism have, of late years, progressed with such gigantic strides, and the discovery of Diamagnetism has opened a new field of research, from which already, such abundant harvests have been gathered, that it was no longer possible to compress within the limits of a single volume, (without expanding it to an inconvenient size) such an account of the present state of Electrical and Magnetic science as the Author proposed to himself to convey. In the present volume the subjects discussed are Electricity, Frictional, and Voltaic; Thermo-Electricity, and Electro-physiology. In the Second Part, which is in active preparation, and which will, it is hoped, be ready in the early part of the ensuing year, it is proposed to attempt a popular account of Magnetism, Diamagnetism, and Electro-dynamics, including a description of the principal Electric Telegraphs.

In the course of the entire work the Author has received much valuable assistance: he wishes particularly to acknowledge the obligations he is under to Mr. Faraday, and to Sir

William Snow Harris; the former has, with his well-known courtesy, been ever ready with his kind explanations, and the latter was good enough to give him an opportunity of witnessing those beautiful experimental demonstrations of the laws of electrical attraction, repulsion, and accumulation, which are described in chapters ii. and v.—and which, having seen and assisted in, he is able to record with the greater satisfaction and confidence. From his late lamented and esteemed friend, Andrew Crosse, Esq., the Author has, from time to time, received much valuable information; nor must he omit to return his thanks to Professor Tyndall, for his kind promptness in placing in his hands his recent beautiful and elaborate memoirs.

The Author wishes in conclusion to observe, that notwithstanding the care and attention he has bestowed on his work, no one can be more sensible than himself to its numerous imperfections; he hopes, however, that it contains no substantial mistakes, and that its errors, whatever they may be, are those rather of *omission* than of *commission*.

Medical School of St. George's Hospital, October, 1855.

CONTENTS.

CHAPTER I.

STATICAL OR FRICTIONAL ELECTRICITY.

CHAPTER II.

PHENOMENA OF FRICTIONAL ELECTRICITY.

CHAPTER III.

PHENOMENA OF FRICTIONAL ELECTRICITY (Continued).

CHAPTER IV.

THE ELECTRICAL MACHINE.

CHAPTER V.

ACCUMULATED ELECTRICITY.

CHAPTER VI.

ATMOSPHERIC ELECTRICITY.

CHAPTER VII.

GALVANIC OR VOLTAIC ELECTRICITY.

CHAPTER VIII.

EFFECTS OF THE VOLTAIC CURRENT.

CHAPTER IX.

EFFECTS OF THE VOLTAIC CURRENT (Continued).

CHAPTER X.

ELECTRO-PHYSIOLOGY.

CHAPTER XI.

CHAPTER XII.

MANUAL

OF

ELECTRICITY, GALVANISM, &c.

STATICAL OR FRICTIONAL ELECTRICITY.

CHAPTER I.

Historical Sketch—Observations of the ancient philosophers—Researches of Gilbert, Boyle, Otto Guericke, Newton, Hawksbee, Wall, Gray, Wheeler, Dufaye, Boze, Winkler, Muschenbroek, Cuneus, Kleist, Watson, Bevis, Wilson, Franklin, Dalibard, Canton, Beccaria, Œpinus, Wilke, Lymner, Cavendish, Coulomb, La Place, Biot, Poisson, Lavoisier, Volta, Saussure.

(1) There is perhaps no branch of Experimental Philosophy which is so popular with all classes and ages as Electricity. The reasons are obvious. It is a science, the general laws of which are susceptible of pleasing demonstration, and its phenomena, from the striking and ocular manner in which they are presented, are calculated to arrest the attention and become fixed on the mind more powerfully than those of any other science. To this may be added its connexion with the most sublime and awful of the agencies of nature; its secret and hidden influence in promoting at one time the decomposition of bodies, and at another time their re-formation: at one time, in its current form, causing the elements of water to separate, and exhibiting them in the form of gases; and at another time, in its condensed form, causing these same gases to re-unite and become again identified with water: *now*, in its current form, exhibiting the most wonderful and sometimes terrible effects on the muscles and limbs of dead animals; and *now*, in its condensed form, moving with a velocity that is beyond conception through the living body, and communicating a shock through fifty or a thousand persons at the same instant: now exhibiting its mighty powers in the fearful thunder-storm; and now, controlled by the ingenuity of man, made the medium for the interchange of thought, and acting as his truthful messenger over land and sea through distances as yet unbounded. With such varied subjects

for contemplation and admiration, it is no wonder if Electricity should be a favourite and a fascinating study.

(2) Common, or *Statical* Electricity, with which we shall first be engaged, although occupying so prominent a place in modern science, cannot be said to date its entrance into physics before the beginning of the eighteenth century. Thales of Miletus, who lived 600 years before the Christian era, is said to have been the first to describe the property possessed by amber to attract and repel light substances when rubbed. In the writings of Theophrastus (B.C. 321), and of Pliny (A.D. 70), the same observations are recorded, and they also speak of the *lapis lyncurius*, supposed to be the same with the modern tourmaline, as possessing similar properties. The power possessed by the torpedo of paralyzing the muscles, and the use which the fish makes of its power for securing its prey, are mentioned by Pliny, and Aristotle, Galen, and Oppian: and the occasional emission of sparks from the human body, when submitted to friction, is alluded to by Eustathius (A.D. 415) in his Commentary on the Iliad of Homer.

No attempt to explain any of these phenomena was made by the writers who narrated them.

(3) In the year 1600, Dr. Gilbert, of Colchester, in a work on Magnetism, mentioned several new facts attributable to electrical agency, and enumerated a variety of substances which enjoyed equally with amber the property of attracting not only light substances, such as feathers and straws, but even stones and metals. Dr. Gilbert also investigated the conditions under which this property was acquired; he found that when the wind blew from the north and east, and was dry, the body was excited in about ten minutes after friction commenced, but that when it was in the south, and the air moist, it was difficult and sometimes impossible to excite it at all.

(4) Boyle, and his contemporary, Otto Guericke, occupied themselves with similar experiments. The latter constructed an electrical machine of a globe of sulphur, and with it discovered electric light, and the fact that a light body when once attracted by an excited electric, was repelled by it, and was incapable of a second attraction until it had been touched by some other body. Newton substituted a globe of glass for one of sulphur, using as a rubber the palm of his hand; he also was the first to show that Electricity may be excited on the side of a disc of glass opposite to the side which was rubbed. Hawksbee also used a glass globe, and made several observations on the light emitted by various bodies by submitting them to friction, without however being at all aware that it was occasioned by Electricity. Dr. Wall compared the light and crackling which attended the friction of amber to lightning and thunder.

(5) The true foundation of Electricity as a science was laid by

Stephen Gray (A.D. 1720—1736). This indefatigable experimentalist first showed that Electricity could be excited by the friction of feathers, hair, silk, linen, woollen, paper, leather, wood, parchment, and gold-beaters' skin; he next discovered the communication of Electricity from excited bodies to bodies incapable of excitation at distances of several hundred feet, and the conducting power of fluids and of the human body; he demonstrated that electric attraction is not proportioned to the mass of matter in a body but to the extent of its surface. In conjunction with Wheeler he discovered the insulating power of silk, resin, hair, glass, and some other substances. He discovered likewise the *fact*, though not the *principle*, of induction, and was on the threshold of the discovery of the two opposite Electricities, an honour reserved for his French contemporary, Dufaye.

(6) This sagacious philosopher re-produced in a more definite form the principles of attraction and repulsion. previously announced by Otto Guericke. He showed that all bodies, whether solid or fluid, could be electrified by an excited tube, provided they were insulated; but his great discovery was that of the two distinct kinds of Electricity, one of which, from the circumstance of its being developed by the friction of glass, rock crystal, precious stones, &c., he called *vitreous;* and the other, from its development by the friction of amber, copal, gum-lac, &c., he termed *resinous*. He showed that bodies having the same kind of Electricity repel each other, but attract bodies charged with Electricity of the other kind; and he proposed that test of the Electricity of any given substance which has ever since his time been adhered to, viz., to charge the suspended light substance with a known species of Electricity, and then to bring near it the body to be examined. If the suspended substance was repelled, the Electricity of both bodies was the same; if attracted, it was different. It is probable, however, that the honour of this capital discovery must be shared between Dufaye and White who was associated with Gray in many of his experiments.

(7) About this time two important additions were made to the electrical machine used by Newton and Hawksbee, viz., that of a prime conductor, consisting of an iron tube suspended by silken strings, introduced by Boze of Wittemberg, and that of a cushion as a substitute for the hand for applying friction suggested by Winkler, of Leipsic. With these improvements the spark from the machine was made to inflame spirits, oil, phosphorus, and several other inflammable substances.

(8) It was in the years 1745 and 1746, that those celebrated experiments, which drew for many succeeding years the almost exclusive attention of men of science to the new subject, and which led the way to the introduction of the Leyden phial,—were made by Kleist, Muschenbroek, and Cuneus. Professor Muschenbroek and his associates,

having observed that electrified bodies exposed to the atmosphere speedily lost their electric virtue, conceived the idea of surrounding them with an insulating substance, by which they thought that their electric power might be preserved for a longer time. Water contained in a glass bottle was accordingly electrified, but no remarkable results were obtained, till one of the party who was holding the bottle attempted to disengage the wire communicating with the prime conductor of a powerful machine; the consequence was, that he received a shock, which, though slight compared with such as are now frequently taken for amusement from the Leyden phial, his fright magnified and exaggerated in an amusing manner. Von Kleist appears to have been the real discoverer of the Leyden phial, though his account of his experiments was so obscurely worded that none of the electricians who repeated them were for some time able to verify his results. The following is an extract from his letter to Dr. Lieberkuhn, of Berlin, dated November 4, 1745, and communicated by him to the Berlin Academy: "When a nail, or a piece of brass wire, is put into a small apothecary's phial and electrified, remarkable effects follow; but the phial must be very dry or warm; I commonly rub it over beforehand with a finger, on which I put some pounded chalk. If a little mercury, or a few drops of spirits of wine, be put into it, the experiment succeeds the better. As soon as this phial and nail are removed from the electrifying glass, or the prime conductor to which it hath been exposed is taken away, it throws out a pencil of flame so long that, with this burning machine in my hand, I have taken about sixty steps in walking about my room; when it is electrified strongly, I can take it into another room, and then fire spirits of wine with it. If while it is electrifying I put my finger or a piece of gold which I hold in my hand to the nail, I receive a shock which stuns my arms and shoulders." In describing the effect produced on himself by taking the shock from a thin glass bowl, Muschenbroek stated, in a letter to Réaumur, that "he felt himself struck in his arms, shoulders, and breast, so that he lost his breath, and was two days before he recovered from the effects of the blow and the terror," adding, "he would not take a second shock for the kingdom of France." Boze, on the other hand, seems to have coveted electrical martyrdom, for he is said to have expressed a wish to die by the electric shock, that the account of his death might furnish an article for the Memoirs of the French Academy of Sciences. Mr. Allamand, on taking a shock, declared "that he lost the use of his breath for some minutes, and then felt so intense a pain along his right arm, that he feared permanent injury from it." Winkler stated that the first time he underwent the experiment, "he suffered great convulsions through his body; that it put his blood into agitation; that he feared an ardent fever, and was obliged to have recourse to cooling medicines!" The lady of this pro-

fessor took the shock twice, and was rendered so weak by it that she could hardly walk. The third time it gave her bleeding at the nose. Such was the alarm with which these early electricians were struck, by a sensation which thousands have since experienced in a much more powerful manner without the slightest inconvenience. It serves to show how cautious we should be in receiving the first accounts of extraordinary discoveries, where the imagination is likely to be affected.

(9) After the first feelings of astonishment were somewhat abated, the circumstances which influenced the force of the shock were examined. Muschenbroek observed that the success of the experiment was impaired if the glass was wet on the outer surface. Dr. Watson showed that the shock might be transmitted through the bodies of several men touching each other, and that the force of the charge depended on the extent of the external surface of the glass in contact with the hand of the operator. Dr. Bevis proved that tin-foil might be substituted successfully for the hand outside and for the water inside the jar; he coated panes of glass in this way, and found that they would receive and retain a charge; and lastly, Dr. Watson coated large jars inside and outside with tin-foil, and thus constructed what is now known as the Leyden phial.

(10) In repeating the experiments with the Leyden phial, Mr. Wilson, of Dublin, discovered the *lateral* shock, having observed that a person standing near the circuit through which the shock is transmitted would sustain a shock, if he were only in contact with or even placed very near any part of the circuit. Many experiments were also made to determine the distance through which the electric shock could be transmitted. Dr. Watson took a prominent part in these investigations. In July, 1747, he conveyed the electric shock across the River Thames, at Westminster Bridge, and a few days after he caused it to make a circuit of two miles at the New River, at Stoke Newington; a circuit of four miles, two of wire and two of dry ground, was accomplished in August; and in the same month he satisfied himself and his friends that "the velocity of the electric matter, in passing through a wire 12,276 feet in length, was instantaneous."

Dr. Watson also distinguished himself by some beautiful experiments on electric light. He was the first to demonstrate the passage of Electricity through a vacuum. He caused the spark from his conductor to pass in the form of coruscations of a bright silver hue through an exhausted tube three feet in length, and he discharged a jar through a vacuum interval of ten inches in the form of a "mass of very bright embodied fire." These experiments were repeated and varied by Smeaton, Canton, and Wilson.

(11) It was in the year 1747 that, in consequence of a communication from Mr. Peter Collinson, a Fellow of the Royal Society of London, to

the Literary Society of Philadelphia, Franklin first directed his attention to Electricity; and from that period till 1754 his experiments and observations were embodied in a series of letters, which were afterwards collected and published. "Nothing," says Priestley, "was ever written upon the subject of Electricity, which was more generally read and admired in all parts of Europe, than these letters. It is not easy to say whether we are most pleased with the simplicity and perspicuity with which they are written, the modesty with which the author proposes every hypothesis of his own, or the noble frankness with which he relates his mistakes when they were corrected by subsequent experiments." The opinion adopted by Franklin with respect to the nature of Electricity differed from that previously submitted by Dufaye. His hypothesis was as follows:—All bodies in their natural state are charged with a certain quantity of Electricity, in each body this quantity being of definite amount. This quantity of Electricity is maintained in equilibrium upon the body by an attraction which the particles of the body have for it, and does not therefore exert any attraction for other bodies. But a body may be invested with more or less Electricity than satisfies its attraction. If it possess more, it is ready to give up the surplus to any body which has less, or to share it with any body in its natural state; if it have less, it is ready to take from any body in its natural state a part of its Electricity, so that each will have less than its natural amount. A body having more than its natural quantity is electrified *positively* or *plus*, and one which has less is electrified *negatively* or *minus*. One electric fluid only is thus supposed to exist, and all electrical phenomena are referable either to its accumulation in bodies in quantities more than their natural share, or to its being withdrawn from them, so as to leave them *minus* their proper portion. Electrical excess then represents the vitreous, and electrical deficiency the resinous Electricities of Dufaye: and hence the terms *positive* and *negative*, for *vitreous* and *resinous*.

(12) In applying this theory to the case of a charged Leyden jar, the inner coating of tin-foil is supposed to have received more than its natural quantity of Electricity, and is therefore electrified *positively* or *plus*, while the outer coating, having had its ordinary quantity of Electricity diminished, is electrified *negatively* or *minus*. When the jar is discharged, the superabundant or plus Electricity of the inside is transferred by the conducting body to the defective or minus Electricity of the outside; Franklin demonstrated by various experiments that the inside and outside coatings are really charged with opposite Electricity, and that during the process of charging exactly as much Electricity is added on one side as is subtracted from the other, and he was thus enabled to offer a satisfactory explanation of what had been previously observed by other

electricians, viz.:—that a jar could not be charged if its external coating were insulated; but though a single jar could not be charged unless its outer coating were in communication with the earth, Franklin showed that a series of jars may be all charged at once by "suspending them on the prime conductor, one hanging on the tail of the other, and a wire from the last to the floor." With the jars thus charged he constructed a battery by separating them, and then putting their insides and outsides in metallic communication.

(13) Another capital discovery of Franklin's related to the place where the Electricity resides in the charged Leyden phial. Having charged a jar he removed the wire by which the Electricity was conveyed from the machine, and poured out the water which served as the inner coating, he found both to be free from Electricity; nevertheless, on pouring fresh water into the jar, he obtained a shock on grasping the outside of the jar in one hand and touching the water with the other. He next laid two metallic plates on a pane of glass and charged it from the machine; on removing the plates he could detect no Electricity in them, but on presenting his finger to the surface of the glass that had been covered with the metal he observed small sparks; he then replaced the metallic plates, and on touching each at the same time he received a shock. From these experiments he drew the conclusion, that it was upon the glass that the Electricity was deposited, and that the conducting coatings "served only like the armature of the loadstone to unite the forces of the several parts, and bring them at once to any point desired."

(14) But the discovery which immortalized the American philosopher, is that in which he connected Electricity with that terrific agent that has so often convulsed the physical world, and which led him to a means of disarming the fury of the lightning flash, and of converting it into a useful element. The similarity between lightning and the electric spark had been suggested by Hawksbee, Wall, and particularly by the Abbé Nollet, who, in the fourth volume of his *Leçons de Physique*, published towards the close of the year 1748, thus expresses himself; "If any one should undertake to prove as a clear consequence of the phenomenon, that thunder is in the hands of nature what Electricity is in ours,—that those wonders which we dispose at our pleasure are only imitations on a small scale of those grand effects which terrify us, and that both depend on the same mechanical agents,—if it were made manifest that a cloud prepared by the effects of the wind, by heat, by a mixture of exhalations, &c., is in relation to a terrestrial object what an electrified body is in relation to a body near it not electrified, I confess that this idea well supported would please me much; and to support it how numerous and specious are the reasons which present themselves to a mind conversant with Electricity. The universality of the electric matter, the readiness of its actions, its instru-

mentality and its activity in giving fire to other bodies, its property of striking bodies externally and internally, even to their smallest parts (the remarkable example we have of this effect even in the Leyden jar experiment, the idea which we might truly adopt in supposing a greater degree of electric power), all these points of analogy which I have been for some time meditating, begin to make me believe that one might, by taking Electricity for the model, form to one's self in regard to thunder and lightning more perfect and more probable ideas than hitherto proposed."

(15) There does not appear to be any published suggestion of Franklin's relative to the identity of lightning and Electricity bearing so early a date as the volume of Nollet's from which the above extract is taken. His letter to Mr. Collinson, in which he gives his reasons for considering them to be the same physical agent, bears no date, but appears to have been written in 1749 or 1750, as he refers to it in a subsequent letter to the same gentleman in 1753, as his former paper, written in 1747, and enlarged and sent to England in 1749. He says, "When a gun-barrel in electrical experiments has but little electrical fire in it, you must approach it very near with your knuckle before you can draw a spark. Give it more fire, and it will give a spark at a greater distance. Two gun-barrels united, and as highly electrified, will give a spark at a still greater distance. But if two gun-barrels electrified will strike at two inches distance and make a loud snap, at what a great distance may ten thousand acres of electrified cloud strike and give its fire, and how loud must be that crack!" He next states the analogies which afford presumptive evidence of the identity of lightning and Electricity. The electrical spark is zig-zag and not straight; so is lightning. Pointed bodies attract Electricity; lightning strikes mountains, trees, spires, masts, chimneys. When different paths are offered to the escape of Electricity, it chooses the best conductor; so does lightning. Electricity fires combustibles; so does lightning. Electricity fuses metals; lightning does the same. Lightning rends bad conductors when it strikes them; so does Electricity when rendered sufficiently strong. Lightning reverses the poles of a magnet; Electricity has the same effect. A stroke of lightning, when it does not kill, often produces blindness; Franklin rendered a pigeon blind by a stroke of Electricity intended to kill it. Lightning destroys animal life; the American philosopher killed a turkey and a hen by electrical shocks.

(16) It was in the June of 1752, that Franklin made his memorable experiment of raising a kite into a thunder-cloud, and of drawing from it sparks with which Leyden jars were charged, and the usual electrical experiments performed. A month earlier, it appears that a French electrician, M. Dalibard, following the minute and circumstantial

directions given by Franklin in his letters to Mr. Collinson, obtained sparks from an apparatus prepared at Marly-la-Ville: and an attempt has lately been made by M. Arago to claim for this philosopher, and Nollet, the honour of having established the identity of lightning and Electricity: it is clear, however, that the just right belongs to Franklin; for although this eminent electrician was a month later in his capital experiment than Dalibard, it was nevertheless at his suggestion, and on his principles, that the arrangements of the Frenchman were made; and indeed, if the honour of the discovery is to be given to the individual who first obtained sparks from an atmospheric apparatus, it belongs neither to Dalibard nor to Franklin, but to an old retired-soldier and carpenter, named Coiffier, who was employed by Dalibard to assist him in his experiments, and who actually first drew a spark from the apparatus when the curé was absent.

(17) The following is the account transmitted to us of Franklin's bold experiment:—"He prepared his kite by making a small cross of two light strips of cedar, the arms of sufficient length to extend to the four corners of a large silk handkerchief stretched upon them; to the extremities of the arms of the cross he tied the corners of the handkerchief. This being properly supplied with a tail, loop, and string, could be raised in the air like a common paper kite, and being made of silk was more capable of bearing rain and wind. To the upright arm of the cross was attached an iron point, the lower end of which was in contact with the string by which the kite was raised, which was a hempen cord. At the lower extremity of this cord, near the observer, a key was fastened: and in order to intercept the Electricity in its descent and prevent it from reaching the person who held the kite, a silk ribbon was tied to the ring of the key, and continued to the hand by which the kite was held."

"Furnished with this apparatus, on the approach of a storm, he went out upon the commons near Philadelphia, accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which would have attended the report of such an attempt, should it prove to be unsuccessful. Having raised the kite, he placed himself under a shed, that the ribbon by which it was held might be kept dry, as it would become a conductor of Electricity when wetted by rain, and so fail to afford that protection for which it was provided. A cloud, apparently charged with thunder, soon passed directly over the kite. He observed the hempen cord; but no bristling of its fibres was apparent, such as was wont to take place when it was electrified. He presented his knuckle to the key, but not the smallest spark was perceptible. The agony of his expectation and suspense can be adequately felt by those only who have entered into the spirit of such experimental researches.

After the lapse of some time he saw that the fibres of the cord near the key bristled, and stood on end. He presented his knuckle to the key and received a strong bright spark. *It was lightning.* The discovery was complete, and Franklin felt that he was immortal."

A shower now fell, and wetting the cord of the kite, improved its conducting power. Sparks in rapid succession were drawn from the key; a Leyden jar was charged by it, and a shock given; and in fine, all the experiments which were wont to be made by Electricity were re-produced, identical in all their concomitant circumstances.

(18) Franklin afterwards raised an insulated metallic rod from one end of his house, and attached to it a chime of bells, which, by ringing, gave notice of the electrical state of the apparatus; and having succeeded in drawing the electric fire from the clouds, he immediately conceived the idea of protecting buildings from lightning by erecting on their highest parts pointed iron wires, or conductors, communicating with the ground. The Electricity of a hovering cloud could thus be carried off slowly and silently; and if the cloud were highly charged, the electric fire would strike in preference the elevated conductors.

(19) These interesting experiments were eagerly repeated in almost every civilized country, with variable success. In France a grand result was obtained by M. de Romas: he constructed a kite seven feet high, which he raised to the height of 550 feet by a string, having a fine wire interwoven through its whole length. On the 26th of August, 1756, flashes of fire, ten feet long and an inch in diameter, were given off from the conductor. In the year 1753, a fatal catastrophe from incautious experiments upon atmospheric Electricity, occurred to Professor Richmann, of St. Petersburg; he had erected an apparatus in the air, making a metallic communication between it and his study, where he provided means for repeating Franklin's experiments: while engaged in describing to his engraver, Solokow, the nature of the apparatus, a thunder-clap was heard, louder and more violent than any which had been remembered at St. Petersburg. Richmann stooped towards the Electrometer to observe the force of the Electricity, and "as he stood in that posture, a great white and bluish fire appeared between the rod of the Electrometer and his head. At the same time a sort of steam or vapour arose, which entirely benumbed the engraver, and made him sink on the ground." Several parts of the apparatus were broken in pieces and scattered about: the doors of the room were torn from their hinges, and the house shaken in every part. The wife of the professor, alarmed by the shock, ran to the room, and found her husband sitting on a chest, which happened to be behind him when he was struck, and leaning against the wall. He appeared to have been instantly struck dead; a red spot was found on his forehead, his shoe was burst open, and a part

of his waistcoat singed; Solokow was at the same time struck senseless. This dreadful accident was occasioned by the neglect on the part of Richmann to provide an arrangement by which the apparatus, when too strongly electrified, might discharge itself into the earth, a precaution that cannot be too strongly urged upon all who attempt experiments in atmospheric Electricity.

(20) The labours of Canton and Beccaria in the field of electrical science stand next in chronological order. The principal discovery of the former was the fact that vitreous substances do not always afford positive Electricity by friction, but that either kind of Electricity may be developed at will in the same glass tube. This he illustrated by drawing a rubber over a tube, one half of which was roughened and the other half polished; the rough part was charged with negative, and the smooth part with positive Electricity. He found also that a glass tube, the surface of which had been made rough by grinding, possessed positive Electricity when excited with oiled silk, but negative when excited with new flannel. Canton also made the useful practical discovery that the exciting power of a rubber may be greatly increased by covering its surface with an amalgam of mercury and tin. This electrician was the first also to demonstrate that air is capable of receiving Electricity by communication. In a paper read at the Royal Society, December 6th, 1753, he announced that the common air of a room might be electrified to a considerable degree, so as not to part with its Electricity for some time. His Electrometer consisted of a pair of dry elder pith-balls suspended by threads of the finest linen. These were contained in a narrow box with a sliding cover, and so disposed that, by holding the box by the extremity of the cover, the balls would hang freely from a pin in the inside. He describes the following method of communicating Electricity to air. "Take a charged phial in one hand, and a lighted candle insulated in the other; and going into any room, bring the wire of the phial very near to the flame of the candle, and hold it there about half a minute, then carry the phial and candle out of the room, and return with the pith-balls suspended and held at arms' length. The balls will begin to separate on entering the room, and will stand an inch and a half or two inches apart, when brought near the middle of it."—*Priestley's History of Electricity*, p. 196.

With Canton also originated those remarkable experiments on induction, or as he expressed it, "relating to bodies immerged in electric atmospheres," which afterwards led Wilke and Œpinus to the method of charging a plate of air like a plate of glass, and to make the most perfect imitation of the phenomena of thunder and lightning.

(21) The electrical researches of Beccaria bear evidence to his extraordinary acuteness and accuracy. He was the first philosopher who

diligently investigated and described the phenomena of a thunder-storm. His account of the circumstances attendant on this majestic spectacle will be given in the proper place. He first showed that the polarity of a needle was determined by the direction in which the electric current passed through it, and that therefore magnetic polarity may be employed to test the species of Electricity with which a thunder-cloud is charged. By extending this analogy to the earth itself, he conjectured that terrestrial magnetism was like that of the needle magnetized by Franklin and Dalibard; the mere effects of permanent currents of natural Electricity established and maintained upon its surface by various physical causes. He alludes to the vast quantity of the electric fluid circulating between different parts of the atmosphere, particularly in storms. "Of such fluid," he says, "I think that some portion is constantly passing through all bodies situate on the earth, especially those which are metallic and ferruginous; and *I imagine that it must be those currents which impress on fire-irons and other similar things the power which they are known to acquire of directing themselves according to the magnetic meridian when they are properly balanced.*" The grand discovery of Oersted is in this paragraph distinctly foreshadowed.

(22) Beccaria's Treatise on Atmospheric Electricity was published in 1753, at Turin, and his "Lettere dell' Ettricismo" at Bologna, in 1758. The latter contain the results of many important investigations. He showed that water is a very imperfect conductor of Electricity; that its conducting power is proportional to its quantity, and that a small quantity of water opposes a powerful resistance to the electric fluid. By discharging shocks through wires placed very near to each other in a tube full of water, he succeeded in making the spark visible in that fluid, and sometimes burst the tubes. He proved (in conjunction with Canton) that a volume of air in a quiescent state might be charged with Electricity; that the Electricity of an electrified body is diminished by that of the air, and that the air parts with its Electricity very slowly. Beccaria also decomposed sulphuret of mercury by the electric spark, and reduced several metals from their oxides; and he seems to have been the first to have noticed the bubbles of gas which rose from water when the electric spark was transmitted through it, though he formed no theory respecting the phenomenon.

(23) The property possessed by certain minerals of becoming electric by heat appears to have been one of the first electrical phenomena that engaged the attention of Œpinus, who, in 1736, published an account of some experiments, in which he showed that for the development of the attractive powers of the tourmaline, a temperature between 99½° and 212° Fahrenheit, was requisite. A more important discovery,

due to this German philosopher (in conjunction with Wilke), was that a plate of air could be charged in a similar manner to a plate of glass, by suspending a board covered with tin-foil over another of equal size in communication with the earth, and giving it a charge of positive Electricity. This experiment was suggested by some remarkable ones of Canton's and Franklin's, in which the grand principle of induction was first clearly demonstrated, and the result led, in Volta's hands, to the discoveries of those useful instruments of electrical research, the *Electrophorus* and the *Condenser*. In the year 1759, Œpinus published, at St. Petersburg, a new theory of Electricity, founded on the following principles:—

1°. The particles of the electric fluid *repel* each other with a force decreasing as the distance increases.

2°. The particles of the electric fluid *attract* the particles of all bodies, and are attracted by them with a force obeying the same law.

3°. The electric fluid exists in the pores of bodies, and while it moves without any obstruction in non-electrics, such as metals, water, &c., it moves with extreme difficulty in electrics, such as glass, resin, &c.

4°. Electrical phenomena are produced either by the transference of the fluid from a body containing more, to another containing less of it, or from its attraction and repulsion when no transference takes place.

Œpinus presented Franklin's theory in a mathematical dress, and showed that, to reconcile it with mathematical statement, it was necessary to assume that between the matter composing the masses of different bodies there exists a mutually repulsive force, acting at sensible distances.

(21) A series of experiments, illustrative of the mutual attraction of bodies dissimilarly electrified, was published by Mr. Robert Lymner, in 1759. In pulling off his stockings in the evening he had remarked occasionally a crackling noise, accompanied by the emission of sparks. He noticed that this phenomenon did not occur with *white silk* stockings, neither did it take place when *two* black or *two* white stockings were put on the same leg; but when a black and a white stocking were put on the one over the other, powerful signs of electrical excitement were manifested on pulling them off, and *each showed the entire shape of the leg, and at a distance of a foot and a half they rushed to meet each other, and remained stuck together with such tenacity that a force of several ounces weight was required to separate them.* He was also enabled to communicate a charge of positive or negative Electricity to a Leyden jar, according as the wire was presented to the *black* or *white* stocking.

In consequence of these experiments Lymner was induced to adopt a modification of Dufaye's theory, and to maintain that of two distinct

fluids not independent of each other, as Dufaye supposed them to be, but co-existent, and by counteracting each other producing all the phenomena of Electricity. He assumed that every body contained in its natural state equal quantities of these fluids; that when *positively* electrified a body does not contain a larger share of electric matter, but a larger portion of one of the active powers, and when *negatively* electrified a larger portion of the other, and not, as Franklin's theory supposes, an actual deficiency of electric matter. Lymner did not make any extensive application of his theory, and it did not, therefore, at the time it was proposed, excite much attention.

(25) The names of Cavendish and Coulomb occur at this period of our history. The former distinguished physicist undertook a mathematical investigation of electrical phenomena, and arrived at results nearly similar to those of Œpinus, with whose researches on the subject he was quite unacquainted. Cavendish also made some valuable experiments on the relative conducting powers of different substances. He found that the electric fluid experiences as much resistance in passing through a column of water *one* inch long as it does in passing through an iron wire, of the same diameter, 400,000,000 inches long; that water, containing in solution one part of salt, conducts 100 times better than fresh water; and that a saturated solution of sea-salt conducts 720 times better than fresh water. He also determined that the quantity of Electricity in coated glass of a certain area increased with the *thinness* of the glass, and that in different coated plates the quantity was as the area of the coated surface *directly*, and as the thickness of the glass *inversely*. By means of the electric spark, Cavendish succeeded in decomposing atmospheric air, and in the month of December, 1787, aided by Gilpin, he demonstrated experimentally to the Royal Society, the formation of nitric acid, by exploding a mixture of seven measures of oxygen gas with three measures of nitrogen. Whether the discovery of the composition of water by transmitting an electric spark through a mixture of oxygen and hydrogen gases can be justly claimed by Cavendish is a disputed question.*

(26) The researches of Coulomb form an epoch in the history of electrical science, laying as they did the foundations of *Electro-statics*. By means of his *balance of torsion* he proved, 1st, that, like gravity, the electrical forces vary *inversely as the square of the distance*; 2nd, that excited bodies when insulated gradually lose their Electricity from two causes, from the surrounding atmosphere being never free from

* See Lardner "On the Steam Engine," seventh edition, p. 303; see also Arago's "Historical Eloge of James Watt," translated by Muirhead, p. 95, *et seq.*, and the Historical Note by Lord Brougham, appended to the same.

conducting particles, and from the incapacity of the best insulators to retain the whole quantity of Electricity with which any body may be charged, there being no substance known altogether impervious to Electricity. Coulomb determined the effect of both of these causes. Adopting the hypothesis of two fluids, this able philosopher investigated experimentally and theoretically the distribution of Electricity on the surface of bodies. He determined the law of its distribution between two conducting bodies in contact, and measured its density. He measured, also, the distribution of the fluid on the surface of a cylinder, and satisfactorily illustrated the doctrine of points, which formed so prominent a part of the researches of Franklin. Coulomb's experiments on the dissipation of Electricity were also important. He found that the momentary dissipation was proportional to the degree of Electricity at the time, and that when the Electricity was moderate its dissipation was not altered in bodies of different kinds or shapes. The temperature and pressure of the atmosphere did not produce any sensible change, but the dissipation was nearly proportional to the *cube* of the quantity of moisture in the air. He found that a thread of gum-lac was the most perfect of all insulators, insulating *ten* times better than a dry silk thread, and he found also that the dissipation of Electricity along insulators was chiefly owing to adhering moisture, but in some measure also to a slight conducting power.

(27) The phenomena of Electricity having, by the labours of Coulomb, been brought within the pale of mixed mathematics, the investigation was pursued by La Place, Biot, and Poisson. The former illustrious mathematician investigated the distribution of Electricity on the surface of ellipsoids of revolution, and he showed that the thickness of the coating of the fluid at the pole was to its thickness at the equator as the equatorial is to the polar diameter, or, what is the same thing, that the repulsive force of the fluid, or its tension at the pole, is to that at the equator as the polar is to the equatorial axis. This examination was extended by Biot to spheroids differing little from a sphere, whatever may be the irregularity of their figure. He likewise determined, analytically, that the losses of Electricity form a geometrical progression when the two surfaces of a jar or plate of coated glass are discharged by successive contacts; and he found that the same law regulates the discharge when a series of jars or plates are placed in communication with each other. It is, however, to Poisson that we are chiefly indebted for having brought the phenomena of Electricity under the dominion of analysis, and placed it on the same level as the more exact sciences. He took as the basis of his investigations, the theory of two fluids, proposed by Lymner and Dufaye, with such modifications and additions as were suggested by the researches of

Coulomb. He deduced theorems for determining the distribution of the electric fluid on the surfaces of two conducting spheres, when they are placed in contact or at any given distance, the truth of which had been established, experimentally, by Coulomb, before the theorems themselves had been investigated. On bodies of elongated forms, or those which have edges, corners, or points, it is shown as a consequence of the theory of two fluids, that the electric fluid accumulates in greater depths about the edges, corners, or points, than in other places. Its expansive force being, therefore, greater at such parts than elsewhere, exceeds the atmospheric pressure and escapes, while at other parts of the surface it is retained.

(28) The Electricity developed during the passage of bodies from the solid or fluid to the gaseous state, was made the subject of a series of experiments, towards the conclusion of the last century, by La Place, Lavoisier, Volta, and Saussure. The bodies which were to be evaporated or dissolved were placed upon an insulating stand, and made to communicate, by a chain or wire, with a Volta's condenser. When sulphuric acid, diluted with three parts of water, was poured upon iron filings, inflammable air was disengaged with brisk effervescence, and at the end of a few minutes the condenser was so highly charged as to yield a strong spark of negative Electricity. Similar results were obtained when charcoal was burnt on a chafing dish, or when fixed air or nitrous gas was generated from powdered chalk by means of sulphuric and nitrous acids. These experiments pointed to natural evaporation as the cause of the disturbance of the general electrical equilibrium of the globe, giving a surplus of positive Electricity to the air and leaving the earth surcharged with negative fluid. The subject engaged particularly the attention of Volta, who was at that time occupied in the investigation of the electric state of the air. In the course of his experiments this distinguished philosopher had availed himself of the power of flame to attract Electricity, and having found that when a taper was placed on the point of his conductor, his Electrometer gave signs of a far larger quantity of Electricity than when it was away, he suggested that the force of storms might be much mitigated by lighting enormous fires on elevated situations, the air being thereby robbed of its Electricity. It does not appear that Volta ever carried this design into effect, though it was suggested by Arago that the conjecture might be tested in Staffordshire, and other English counties which abound in iron furnaces.

(29) Having thus briefly sketched the prominent features in the history of Statical Electricity up to the period of the commencement of the present century, we proceed to a popular investigation of the phenomena as they are at present understood.

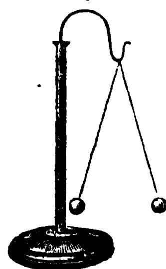
CHAPTER II.

Primary phenomena of frictional Electricity—Attraction and repulsion—Positive and negative conditions—Conductors and non-conductors—Electroscopes and Electrometers—Pyro-Electricity of minerals—Laws of electrical attraction and repulsion.

(30) *Primary phenomena.*—For illustrating the fundamental phenomena of Electricity we can employ no materials either simpler or better than those used by Stephen Gray in 1730.

1°. If a stout glass tube, about an inch in diameter and 18 or 20 inches long, be made dry and warm, and then briskly rubbed for a few seconds with a dry soft silk handkerchief, or better with a piece of oiled silk the rough side of which has been smeared over with "mosaic gold," and then held near a pith-ball suspended by a long silk thread, the ball will be attracted, and after adhering to the glass for a short time, will be repelled to a considerable distance, nor will it be again attracted until it has touched some body in conducting communication with the earth, and thus given up the Electricity which it had acquired from the tube; or until, by remaining undisturbed for some time, it has lost it by dissipation into the atmosphere.

2°. If a stick of common sealing-wax be rubbed with a piece of dry flannel, or if a piece of gutta percha such as is used for the soles of shoes be lightly rubbed on the sleeve of the coat, and if either be brought near the pith-ball while under the influence of the Electricity from the glass, it will *attract* it powerfully, but soon repel it, when the excited glass will again attract it, and the ball may thus be kept for some time vibrating between the two substances.


Fig. 1.

3°. If two pith-balls be suspended by two silk threads and excited either by the glass or by the resin, it will be observed on removing the exciting material, that the balls no longer fall into the vertical position, but stand apart at a greater or less angle, apparently repelling one another as shown in Fig. 1; the balls have thus acquired properties relatively to each other, similar to those which the glass and single ball exhibited after contact in the preceding experiment.

4°. If the pith-balls be suspended by thin metallic wires, or threads, or if the silk filaments be moistened, it will be found impossible to excite

them *permanently*; for the moment the glass, resin, or gutta percha is removed, they return to their original condition.

In order to make these interesting phenomena visible at a considerable distance, the pith-balls may be advantageously re-placed by skeleton globes made by gumming together cross strips of common writing paper; these globes may be two or three inches in diameter, and if the paper be smoothly and evenly cut, they will retain an electrical charge for a long time.

(31) From these simple experiments we learn several important electrical facts:—

1°. That *vitreous* substances, such as glass, become electrical by being rubbed with certain other substances.

2°. That in this state they attract light bodies.

3°. That having once attracted they afterwards repel them.

4°. That resinous substances, such as sealing-wax, and gutta percha, are also capable of receiving electrical excitation by being rubbed.

5°. That *they* also attract and then repel light bodies.

6°. That though excited glass and excited resin agree in their property of attracting light matter, the property called forth by friction in each is different, for one attracts what the other repels, and *vice versâ*.

7°. That bodies charged with the same kind of Electricity exhibit a disposition to *repel* each other.

8°. That in order that they shall retain for any length of time the Electricity communicated to them, they must be insulated from the earth.

9°. That silk is a substance which possesses this power of insulation.

10° That metals and a film of water do not possess this power.

(32) But certain other phenomena attend the excitation of glass and resin: *e.g.* if either be rubbed briskly in the dark while dry and warm, a stream of light will be perceived, a slight crackling noise will be heard, and if the hand or face be held near, a sensation similar to that felt on touching a cobweb will be experienced.

(33) The difference which in the foregoing experiments we perceived between bodies such as silk, glass, and gutta percha, and others, such as cotton, thread, and metal, arises from the circumstance that the former class of substances conducts Electricity very badly, while the latter offers a ready passage to the same. On this account bodies have been divided into two great groups—*conductors* and *non-conductors*; an arrangement useful and sufficiently correct for general purposes, though the recent researches of Faraday and others have shown us, that as there are in reality no substances which can strictly be called perfect conductors of Electricity, so there are none which absolutely refuse a passage to this agent. Conductors and non-conductors (so called) differ only in the degree of their conducting and insulating power; and all known sub-

stances may be regarded as links of the same chain, at one end of which may be placed the best conductor and at the other the best insulator.

(34) Gutta percha as an insulator is equal to shell-lac. It is also an excellent substance for the excitement of negative Electricity, and might probably be used instead of a plate of glass in the construction of an electrical machine. As it comes from the manufacturer it is not however all equally good, but by warming a piece which is found to conduct, in a current of hot air, and by stretching and doubling it up, and kneading it for some time between the fingers, it becomes as good an insulator as the best. Faraday found that after a piece of gutta percha had been soaked in water for four days, it insulated as well as ever after being wiped and exposed for a few hours to the air. He found this substance very useful in his experiments in the form of sheet, or rod, or filament. Thus, being tough and flexible when cold, as well as soft when hot, it serves better than shell-lac in many cases where the brittleness of the latter is an inconvenience. It makes very good handles for carriers of Electricity in experiments on induction, not being liable to fracture: in the form of a thin band or string it makes an excellent insulating suspender; a piece of it in sheet makes a most convenient insulating basis for anything placed on it. It forms good insulating plugs for the stems of gold-leaf Electrometers when they pass through sheltering tubes; and larger plugs supply good insulating feet, for extemporary electrical arrangements; cylinders of it, half an inch or more in diameter, have great stiffness and form excellent insulating pillars. In reference to its power for exciting negative Electricity, Faraday observes that it is hardly possible to take one of the soles sold by the shoemakers out of paper or into the hand without exciting it to such a degree, as to open the leaves of an Electrometer one or more inches; or, if it be unelectrified, the slightest passage over the hand or face, the clothes, or almost any other substance, gives it an electric state. Some of the gutta percha is sold in very thin sheets resembling in general appearance oiled silk; and if a strip of this be drawn through the fingers, it is so electric as to adhere to the hand or attract pieces of paper.

(35) Mr. Barlow (*Phil. Mag.*, vol. xxxvii. 1850, p. 428,) observes, that if a sheet of about four or five feet superficial area be laid on a surface, or held against the wall of a room, and rubbed with the hand or a silk handkerchief, and then carefully removed by the extreme edges, and held suspended in the air, it will give off a brush-like spark of several inches in length to the knob of any conducting surface presented to it; a similar effect may be produced by causing the sheet of gutta percha to be passed once over one, or between two rubbing surfaces, but in order to obtain the best effect the hand should pass over the rubbing surface at an angle of

about 10°, a greater or less angle being, according to Mr. Barlow's experiments, less favourable to the development of Electricity; the effect is also much increased by applying a second rubber of silk or horse-hair outside the strip; the quantity of Electricity developed increasing with the surface of the gutta percha.

Gutta percha may be excited both positively and negatively. If a strip about two inches wide and two feet long be laid on a surface and rubbed, the two extremities when suspended in the air repel each other, and the Electricity is *resinous*; but if the strip be folded double and rubbed, the upper side exhibits *resinous* and the lower side *vitreous* Electricity, and the two extremities attract each other.

(36) Among good conducting substances may be classed all metals, charcoal, strong acid, water, steam, smoke, and all vegetable and animal substances containing water; while among the more or less perfect insulators may be included, gutta percha, shell-lac, amber, resins, sulphur, glass, different transparent gems, silk, feathers, air, and all dry gases, gun cotton, and organic substances perfectly free from water, &c. A substance belonging to the first class when placed upon one in the second list, is said to be insulated from the earth. Atmospheric air must, it is clear, be ranked among the most perfect non-conducting bodies, for if it gave a free passage to Electricity, the electrical effects excited on the surface of any body surrounded with it would quickly disappear, and no permanent charge could be communicated: but this is contrary to experience. Water, on the other hand, whether in the liquid or vaporous form, being a conductor, though of an order very inferior to that of the metals, affects in a very important manner all electrical experiments, as it is constantly present in the atmosphere in greater or less quantity, hence one of the reasons why electrical experiments are made with more facility, and the desired effects produced with more certainty and success in cold and dry weather, when the atmosphere holds but little aqueous vapour suspended in it; another injurious tendency of the watery vapour in the atmosphere is, that which it has to become deposited on the surfaces of bodies, thereby destroying their insulating power. The insulating supports of electrical apparatus are usually made of glass on which moisture is very readily deposited; they should therefore be coated with a thin layer of gum-lac dissolved in spirits of wine, or for delicate experiments be made altogether of shell-lac, or gutta percha.

(37) The nature of conduction has received much elucidation from the beautiful experiments of Faraday (*Phil. Trans.* 1833). He found that though the insulating power of ice was not effective with Electricity of exalted intensity, yet that the thinnest film was sufficient to obstruct altogether the circulation of Electricity in a very powerful galvanic

battery; chloride of lead, chloride of silver, sulphuret of antimony, and a great number of other salts possessed the same property, that, namely, of stopping completely the transmission of the electrical current while solid, but allowing its ready passage when liquefied. Other bodies, such as sulphur, phosphorus, orpiment, realgar, spermaceti, sugar, shell-lac, &c., refused a passage to the current, whether liquid or solid.

Faraday gives the following conditions of electric conduction in bodies, which, though they apply chiefly to voltaic Electricity (under which division of our subject we shall further consider them), are yet true within certain limits for ordinary Electricity.

1°. All bodies from metals to lac and gases conduct Electricity in the same manner, but in very different degrees.

2°. Conducting power is in some bodies powerfully increased by heat, and in others diminished; yet without our perceiving any accompanying electrical difference either in the bodies, or in the changes occasioned by the Electricity conducted.

3°. There are many bodies which insulate Electricity of low intensity, when solid, but conduct it very freely when fluid, and are then decomposed by it.

4°. But there are many fluid bodies which do not sensibly conduct Electricity of this low intensity; there are some which conduct it and are not decomposed, nor is fluidity essential to decomposition.

5°. There is but one substance (periodide of mercury) which, insulating a voltaic current when solid and conducting it when fluid, is not decomposed in the latter case.

6°. There is no electrical distinction of conduction which can as yet be drawn between bodies supposed to be elementary and those known to be compounds.

(38) In a subsequent paper (*Phil. Trans.* 1835), Faraday expresses his conviction that insulation and conduction depend upon the same molecular action of the dielectrics concerned,—are only extreme degrees of one common condition or effect, and in any sufficient mathematical theory of Electricity must be taken as cases of the same kind; they are the same in principle and action, except that in conduction an effect common to both is raised to the highest degree, whereas in insulation it occurs in the best cases only in an almost insensible quantity. The beautiful experiments of Wheatstone have shown that even in metals *time* enters as an element into the conditions of conduction, affording therefore a proof of retardation; and Faraday has been able to trace the progress of conduction as it were step by step through masses of spermaceti, glass, and shell-lac, acknowledged insulators; but retardation is in the latter case *insulation*, and there seems no reason for refusing the same relation to the same exhibition of force in metals.

(39) In the following list the bodies are arranged in their order of conducting power, according to the present state of knowledge on the subject, and though probably not absolutely correct, it will serve to show how insensibly conductors and non-conductors merge into each other.

All the metals.
Well burnt charcoal.
Plumbago.
Concentrated acids.
Powdered charcoal.
Dilute acids.
Saline solutions.
Metallic ores.
Animal fluids.
Sea water.
Spring water.
Rain water.
Ice above 13° Fahr
Snow.
Living vegetables.
Living animals.
Flame smoke.
Steam.
Salts soluble in water.
Rarefied air.
Vapour of alcohol.
Vapour of ether.
Moist earth and stones.
Powdered glass.
Flowers of sulphur.
Dry metallic oxides.
Oils, the heaviest the best.
Ashes of vegetable bodies.
Ashes of animal bodies.
Many transparent crystals dry.
Ice below 13° Fahr.
Phosphorus.
Lime.
Dry chalk.
Native carbonate of barytes.
Lycopodium.
Caoutchouc.
Camphor.
Some siliceous and argillaceous stones.
Dry marble.
Porcelain.
Dry vegetable bodies.
Baked wood.
Dry gases and air.
Leather.
Parchment.
Dry paper.
Feathers.
Hair
Wool.
Dyed silk.
Bleached silk.
Raw silk.
Transparent gems.
Diamond.
Mica.
All vitrifications.
Glass.
Jet.
Wax.
Sulphur.
Resins.
Amber.
Shell-lac.
Gutta percha.

(40) *Opposite Electricities.*—We have seen that excited resin and excited glass, though they both attract light substances, exhibit each a *different kind of force.* Hence the name of resinous Electricity as

applied to the former, and of vitreous as applied to the latter. These terms are, however, very objectionable, implying, as they do, that when vitreous bodies are excited they are always electrified with one species of Electricity, and that when resinous bodies are excited they are always electrified with the other. But this is by no means the case; for example:

1°. When a glass rod is rubbed with a woollen cloth, it repels a pith-ball which it has once attracted: but if the cloth be presented, it will be found to attract the excited ball. We hence conclude, that as the glass was *vitreously* electrified, the woollen cloth must be *resinously* electrified.

2°. When a stick of sealing-wax is rubbed with a woollen cloth, it repels a pith-ball which it has once attracted; but if the cloth be presented it will be found to attract the excited ball. Hence, by a similar reasoning, we are led to the inference that the cloth is *vitreously* electrified.

3°. When a piece of polished glass is rubbed, first with a woollen cloth and then with the fur of a cat, and examined after each excitation by a pith-ball, it is found in the first case *vitreous*, and in the second *resinous*. A woollen cloth and a piece of glass may thus be made to exhibit both kinds of Electricity; the terms vitreous and resinous do not therefore convey to the mind a proper impression of the nature of the two forces.

(41) The terms *positive* and *negative*, though they take their origin in a theory of Electricity which is not now recognized as compatible with observed phenomena, are less objectionable, and have accordingly partially superseded the other terms. *Positive* Electricity, then, is that which is produced upon polished glass when rubbed with a woollen cloth; and *negative* Electricity is that which is produced upon a stick of sealing-wax when rubbed. *One kind of Electricity cannot be produced without the other; and of two substances which by mutual friction excite Electricity, one is invariably positive, and the other negative, after the friction.*

(42) If two persons stand on two stools with glass legs, and one strike the other two or three times with a well-dried cat's fur, he that strikes will have his body charged *positively*, and he that is struck will be electrified *negatively*. A spark may, in fact, be sometimes obtained from the face of either, by a person in contact with the earth. There is no substance so easily excited as the fur of a cat; and most persons are aware of the fact, that if in dry weather the hand be passed briskly over the back of a living cat, the hairs will frequently bristle, and be attracted by the hand, and sometimes a crackling noise will be heard, and a spark obtained. These effects are occasionaly observed with the

human hair, which, when clean, dry, and free from grease, is electrified with great facility by friction, and this is especially the case with fair hair which is in general fine and pliable. Even in damp weather, if a person stand on an insulating stool, and connect himself with a condenser connected with a gold leaf Electroscope, and any one standing on the floor draw a comb rapidly through his hair, on drawing back the uninsulated plate of the condenser, the gold leaves of the Electroscope will diverge with *positive* Electricity; if the person using the comb stand on the stool and connect himself with the condenser, as he combs the gold leaves will open with *negative* Electricity. In dry weather the condenser is not required for this experiment.

(43) The following table given by Singer (*Elements of Electricity*, p. 33), on the authority of Cavallo, exhibits these effects between a variety of substances.

	Is rendered	By friction with
The back of a cat	Positive	Every substance with which it has hitherto been tried.
Smooth glass	Positive	Every substance hitherto tried except the back of a cat.
Rough glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woollen cloth, quills, wood, paper, sealing wax, white wax, the human hand.
Tourmaline	Positive	Amber, blast of air from bellows.
	Negative	Diamonds, the human hand.
Hare's skin	Positive	Metals, silk, loadstone, leather, hand, paper, baked wood.
	Negative	Other finer furs.
White silk	Positive	Black silk, metals, black cloth.
	Negative	Paper, hand, hair, weasel's skin.
Black silk	Positive	Sealing wax.
	Negative	Hare, weasel, and ferret fur, loadstone, brass, silver, iron, hand, white silk.
Sealing wax	Positive	Some metals.
	Negative	Hair, weasel, and ferret fur, hand, leather, woollen cloth, paper, some metals.
Baked wood	Positive	Silk.
	Negative	Flannel.

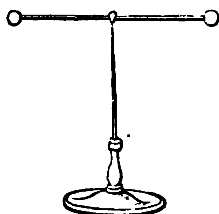
Singer found that sealing-wax is rendered negative by friction with iron, steel, plumbago, lead, and bismuth; and he remarks that in order to arrive at an accurate conclusion, many repetitions of each experiment are necessary, as the least difference in the conditions will occasion singular varieties of result; for example, positive Electricity may be excited in one stick of sealing wax and negative in another, if the former have its surface scratched and the latter be perfectly smooth.

(44) *Electroscopic Apparatus.*—Instruments for indicating the pre-

sence and kind of Electricity are called *Electroscopes;* those by which its quality under various conditions is measured, are called *Electrometers.* Various forms have been given to both classes of instruments, the necessary conditions being that they should be very light, and be capable of moving on the application of the smallest force. A pith-ball, or a paper skeleton globe suspended by a silk thread is, in many cases, sufficient to detect the presence and species of Electricity on a body. It may first be charged by touching it with an excited glass rod, and the body to be examined, then brought near it, if it attract the ball, its Electricity is *negative,* if it repel it, it is *positive;* if it have no effect on the ball it is not electrified, or at least not sufficiently so to produce a force strong enough to overcome the rigidity of the silk string. A more delicate test is a strip of Dutch metal attached to a slip of paper, and suspended from a stick of sealing wax.

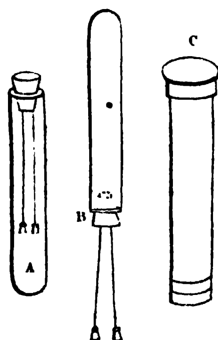
(45) The Electroscope of Gilbert and Haüy consisted of a light metallic needle, terminated at each end by a light pith-ball covered with gold leaf, and supported horizontally by a cap at its centre on a fine point. The attractive and repulsive action of any electrified body presented to one of the balls being indicated by the movements of the needle.

Fig. 2.



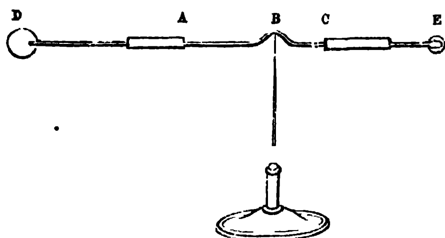
Canton's Electroscope consisted of a pair of pith-balls suspended by fine linen threads (20), which Cavallo modified and made portable by fitting it up, as shown in Fig. 3, where B shows the instrument in a state of action. When it is unloosed, the end B, carrying the pith-balls, is screwed off, and the balls are put into the glass tube A, which serves for a handle. This glass case is three inches long and three-tenths of an inch wide, and half of it is covered with sealing wax. A cork, tapering at both ends, is made to fit the mouth of the tube, and to one end are fixed two fine silver wires, carrying two small cones of dry elder pith. The case of the Electrometer C, encloses at one end a piece of amber for giving negative Electricity, and at the other end a piece of ivory insulated upon a piece of amber, for giving positive Electricity to the balls when rubbed with a piece of woollen.

Fig. 3.



(46) An excellent arrangement of the balanced needle Electroscope

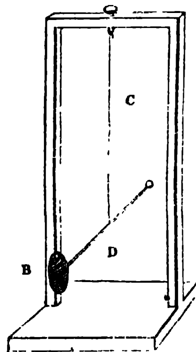
Fig. 4.



is shown in Fig. 4. It consists of a short bent brass wire, A, B, C, to either end of which is fixed a reed, so as to form arms of unequal length. The longer arm carries, at its extremity, a disc of gilt paper, D, about half an inch in diameter, and the shorter arm a small metallic ball, E. The whole is balanced on a finely pointed wire, supported on a rod of varnished glass. The arms are elongated or contracted, and the balance thus adjusted by sliding the reeds upon the wire. The disc, D, is electrified either positively or negatively, and the body, the nature of the Electricity of which is to be examined, is presented to it. If we desire merely to detect the presence of Electricity by its attractive force, we uninsulate the needle by hanging a metallic wire from the pointed rod of support, and then present the excited substance to the disc D.

(47) A still more delicate Electroscope, and one which retains its charge for a long time, even under unfavourable circumstances, such for instance, as in a crowded room, is made by suspending from a wooden frame, by a fine silk or glass filament, C (Fig. 5), a delicate rod of lac, D, carrying at one of its ends a gilt paper disc, B. This disc, in its natural state, will be attracted by any electrified body, but if a charge of positive or negative Electricity be previously given to it, it will be attracted or repelled, in accordance with electrical laws; and as its indications are visible at considerable distances, it is a form of Electroscope well adapted for the lecture room. A stick of lac, carrying at one end a gilt paper disc, forms a very convenient apparatus for conveying small charges of Electricity from one body to another; the paper should be smoothly gilt and the edges free from asperities.

Fig. 5.



(48) Fig. 6 represents Sir William Snow Harris's Electroscope, which acts on the principle of divergence. A small elliptical ring of metal, *a*, is attached obliquely to a small brass rod, *a b*, by the intervention of a short tube of brass at *a*: the rod *a b* terminates in a brass ball, *b*, and is insulated through the substance of the wood ball, *n*.

Two arms of brass, *r r*, are fixed vertically in opposite directions on the extremities of the long diameter of the ring, and terminate in small balls; and in the direction of the shorter diameter within the ring there

is a delicate axis set on extremely fine points: this axis carries, by means of short vertical pins, two light reeds of straw, *s s*, terminating in balls of pith, and constituting a long index, corresponding in length to the fixed arms abovementioned.

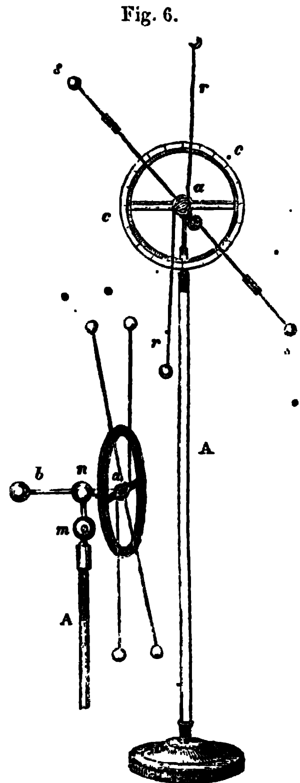
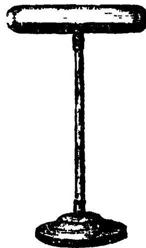


Fig. 6.

The index thus circumstanced is susceptible of an extremely minute force; its tendency to a vertical position is regulated by small sliders of straw, moveable with sufficient friction on either side of the axis.

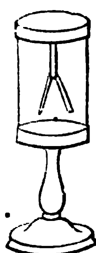
To mark the angular position of the index in any given case, there is a narrow graduated ring of card-board or ivory placed behind it. The graduated circle is supported on a transverse rod of glass by the intervention of wood caps, and is sustained by means of the brass tube, *a*, in which the glass rod is fixed.



The whole is insulated on a long rod of glass, A, by means of wood caps terminating in spherical ends. In this arrangement, as is evident, the index diverges from the fixed arms whenever an electrical charge is communicated to the ball *b*, as shown in the lower figure. The instrument is occasionally placed out of the vertical position at any required angle by means of a joint at *m*, and all the insulating portions are carefully varnished with a solution of shell-lac in alcohol.

This instrument is, to a certain extent, an *Electrometer*, as well as an *Electroscope*, but its applications are, as Sir W. Harris observes, very limited, for though the amount of divergence does increase with the quantity of Electricity in operation, we are not able to ascertain the ratio of increase because of the diminishing force of repulsion as the divergence increases.

(49) But the most elegant and the most generally useful of this class of instruments is the gold leaf Electrometer, invented by the Rev. Mr. Bennett, and improved by Mr. Singer. The original instrument is shown in Fig. 7, and is thus described by its author. "It consists of two slips of gold leaf suspended in a glass. The foot may be


Fig. 7.

made of wood or of metal; the cap of metal. The cap is made flat on the top, that plates, books, evaporating water, or other things to be electrified, may be conveniently placed upon it. The cap is about an inch wider in diameter than the glass, and its rim about three quarters of an inch broad, which hangs parallel to the glass to turn off the rain and keep it sufficiently insulated. Within this is another circular rim, about half as broad as the other, which is lined with silk velvet, and fits close on the outside of the glass; thus the cap fits well, and may be easily taken off to repair any accident happening to the leaf gold Within this is a tin tube, hanging from the centre of the cap, somewhat longer than the depth of the inner rim. In the tube a small peg is placed, and may be occasionally taken out. To the peg, which is made round at one end and flat at the other, two slips of gold leaf are fastened, with paste, gum-water, or varnish. These slips, suspended by the peg, and that in the tube, fast to the centre of the cap, hang in the middle of the glass, about three inches long and a quarter of an inch broad. In one side of the cap there is a small tube to place wires in. It is evident that without the glass the gold leaf would be so agitated by the least motion of the air that it would be useless; and if the Electricity should be communicated to the surface of the glass it would interfere with the repulsion of the gold leaf, therefore two long pieces of tin-foil are fastened with varnish to the two opposite sides of the internal surface of the glass, where the gold leaf may be expected to strike, and in connexion with the foot. The upper end of the glass is covered and lined with sealing wax as low as the outermost rim, to make its insulation the more perfect."

Mr. Singer, reflecting that the perfection of insulators is constantly diminished by the deposition of moisture from the atmosphere on their surfaces, and that this deposition would necessarily be retarded by enclosing the insulator within a narrow channel, was led to make the capital improvement in Bennett's Electroscope, illustrated in Fig. 8. The insulation is here made to depend on a glass tube, four inches long and one fourth of an inch internal diameter, covered, both on the inside and outside, with sealing-wax, and having a brass wire of a sixteenth or twelfth of an inch thick and five inches long, passing through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed with a plug of silk or of gutta percha, which keeps it concentric with the internal diameter of the tube: a brass cap,

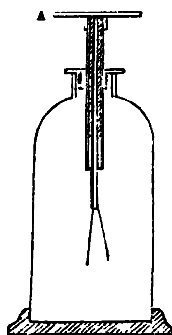


Fig. 8.

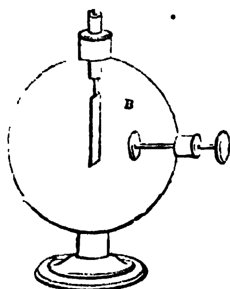
A, is screwed upon the upper part of this wire; it serves to limit the atmosphere from free contact with the outside of the tube, and at the same time defends its inside from dust. To the lower part of the wire the gold leaves are fastened.—*Singer's Electricity.*

(50) The process of applying or replacing the gold leaves is very tedious and difficult unless proper means are resorted to in their management. In the first place, leaf of the best quality should be employed, and it should be cut on a hard leather cushion, with a clean flat dry knife. The edge of the knife should be drawn with pressure over the slip parallel to one of the sides of the leaf. When cut, the slip is raised from the cushion by applying to it a small short slip of gilt paper, gently moistened at one end with the lips, and in adjusting the leaves on the instrument a very thin slip of gilt cork should be inserted between them in order to separate them a little, so as to allow of their hanging parallel and free without touching.—*Harris's Rudimentary Electricity.*

The mode of manipulation with the gold leaf Electroscope and the precautions requisite in interpreting its indications, will be best understood after we have investigated that important class of electrical phenomena comprehended under the name of induction.

(51) A gold leaf Electroscope of great delicacy, in which a *single* leaf is employed, was invented by Dr. Robert Hare, of the university of Pennsylvania, (*Silliman's Journal*, vol. xxv.) The leaf, about three inches long and three-tenths of an inch wide, is suspended, according to Singer's method, in the centre of a globular or other shaped glass vessel, from a brass wire surmounted with a brass cap. A similar rod of brass, carrying at each end a small disc of brass or gilt wood, about half an inch in diameter, passes through the side of the vessel, so that the internal disc shall be immediately opposite the lower end of the suspended leaf. This wire slides freely through a socket, so that the internal disc may be adjusted at any required distance from the leaf.

Fig. 9.



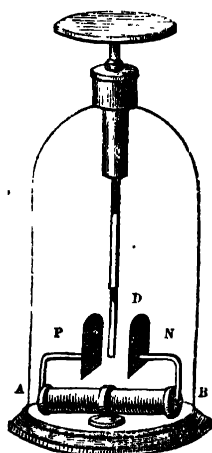
This instrument is shown in Fig. 9. When it is employed to detect Electricity the lateral wire is uninsulated by hanging a wire from it to the earth, and the body to be tested is brought into contact with the cap. If the distance between the gold leaf and the disc, B, is very small, the most minute force of attraction is made apparent. When it is required to determine the *kind* of Electricity with which a body is charged, the insulated disc, B, is brought as near as possible to the leaf, and electrified either *positively* (with excited glass), or *negatively* (with excited

wax), the gold leaf is first attracted and then repelled. Under these circumstances the body to be tested is brought into contact with the cap, or with D; if its Electricity be of the same nature as that with which the leaf is charged, the latter will diverge more freely; if of the contrary nature it will collapse towards B.

Mr. Gassiot has improved this form of Electroscope (*Phil. Trans.*, 1844), by placing a gilt disc on *each side* of the gold leaf, and with this modification of the instrument he obtained signs of tension in a single cell of the voltaic battery.

(52) By substituting for the gilt discs, in Hare's Electroscope, the poles of the dry electric column the sensibility of the instrument is wonderfully increased. An apparatus of this kind was first constructed, in 1820, by Bohnenberger. It is shown in Fig. 10, as subsequently improved by Becquerel. A B is a dry electric column of about 500 pairs, about a quarter of an inch in diameter, occupying, when the plates are pressed together, from two to two and a half inches in length. To the ends of this pile are adapted two bent wires, terminating in two gilded plates, P, N, which constitute the poles of the battery. These plates, which are two inches long and half an inch wide, are parallel and opposite to each other, the gold leaf, D, being suspended between them. Now, if the leaf hang exactly midway between the terminal plates of the column, it will be equally attracted by each, and will therefore remain in a state of repose, but the most minute quantity of Electricity communicated to the cap of the instrument will disturb this neutral condition of the leaf, and it will immediately move towards the plate which has the opposite polarity. Mr. Sturgeon describes (*Lectures on Galvanism*, 1843) a somewhat similar arrangement, the delicacy of which he states to be such, that the cap, being of zinc and of the size of a sixpence, the pendent leaf is caused to lean towards the negative pole by merely pressing a plate of copper, also the size of a sixpence, upon it, and when the copper is suddenly lifted up the leaf strikes. The different electrical states of the *inside* and *outside* of various articles of clothing were readily ascertained by this delicate Electroscope.

Fig. 10.



(53) *Pyro-Electricity of Minerals.*—But it is not by friction alone that Electricity is developed; the natural Electricity of a substance is disturbed by almost every form of mechanical change to which it can be submitted; mere pressure is quite sufficient for the purpose. If two pieces of common window glass be pressed firmly together, and

in this state brought near a gold leaf Electrometer, no disturbance of the leaves will ensue; but if they be suddenly separated, and one piece brought near the Electrometer (being held by a handle of sealing-wax), the presence of free Electricity will be demonstrated, one piece proving to be positive, and the other negative.

If sulphur be poured whilst melted into a conical glass, and furnished with an insulating handle, or a piece of glass or silk, it will, when cold, indicate no free Electricity, but on removing the cone of sulphur from the glass, and presenting it to the Electroscope, it will be found to be negatively excited, the glass itself being positive.

(54) Some minerals become electrical by being heated; the tourmaline possesses this property in a particularly marked manner. This mineral crystallizes in long slender prisms, its primitive form being an obtuse rhomb, the axis of which coincides with the axis of the prism. By friction it acquires *positive* or *vitreous* Electricity, and when two tourmalines are rubbed together, the one acquires positive and the other negative Electricity. The pyro-electricity of the tourmaline was minutely investigated by Haüy, who found that the Electricity was distributed over the crystal nearly in the same manner as on a cylindrical conductor, electrified by induction (71). The *positive* Electricity was at a maximum near one extremity of the crystal, and gradually diminished towards the middle, where it disappeared. Here the *negative* Electricity appeared very faintly, and gradually increased towards the other end of the crystal near which it was at a maximum. If a tourmaline, when rendered electrical by heat, be broken in pieces, each piece will have a positive and a negative pole, from whichever end of the crystal it be broken, the extremity of the fragment always possessing the same kind of Electricity as that of the pole to which it was nearest when it formed part of the crystal. As we have already stated (23), it had been noticed by Œpinus that the tourmaline becomes electrical only at a particular temperature, above and below which its Electricity disappears. It was found, however, by Haüy that at a certain degree of coldness, the Electricity of the mineral re-appears, and gradually increases till it reaches its maximum, when it again gradually disappears; but what is very remarkable, the Electricity is not the same as before, the pole that was formerly *positive* being now *negative*.

(55) Sir David Brewster has given the following list of minerals and artificial crystals in which he has detected the property of becoming electrical by heat:—

MINERALS.

Calcareous Spar.	Sulphate of Barytes.
Beryl, Yellow.	Sulphate of Strontia.

Carbonate of Lead.
Diopside.
Fluor Spar (red).
Fluor Spar (blue).
Diamond.
Yellow Orpiment.
Analcime.
Amethyst.
Quartz.
Idocrase.
Mellite. (?)
Sulphur (native).
Garnet.
Dichroite.

ARTIFICIAL CRYSTALS.

Tartrate of Potash and Soda.
Tartaric Acid.
Oxalate of Ammonia.
Chlorate of Potash.
Sulphate of Magnesia and Soda.
Sulphate of Ammonia.
Sulphate of Iron.
Sulphate of Magnesia.
Prussiate of Potash.
Sugar.
Acetate of Lead.
Carbonate of Potash.
Citric Acid.
Corrosive Sublimate.

To the above list must be added *oxalate of lime*, which, according to Faraday, stands at the head of all bodies yet tried, in its power of becoming positively electrical by heat. At a temperature of about 300° Fahrenheit, it becomes so strongly electrical when stirred in a basin with a platina spatula, that it cannot be collected together; and when its particles are well excited and shaken on the top of a gold leaf Electrometer, the leaves diverge two or three inches. When this salt is excited in a silver basin, and left out of contact with the air, it continues electrical for a great length of time, proving its very bad conducting power, in which it probably surpasses all other bodies.

Fig. 11.

(56) *Electrometers; law of electrical attraction and repulsion.*—It has been mentioned (26) that the law of electrical attraction and repulsion was determined by Coulomb with the aid of his Torsion Electrometer. This exquisite contrivance is shown in Fig. 11, where A B C D is a glass cylinder, which is covered with a plate of glass, A B, thirteen inches in diameter. This plate is perforated with two holes, *e* and *a*, the former being intended to receive a tube of glass, *e* G, two feet high, carrying on its upper end a

torsion Micrometer, consisting of a graduated circle, M N, an index, M, and a pair of pincers, opened and shut by a ring, for holding a slender silver or glass wire, G H, whose lower end, H, is also grasped by a similar pair of pincers made of copper, and about a line in diameter. Through a hole in these copper pincers there passes a horizontal needle, *c d*. This needle consists of a silk thread or straw, covered with sealing-wax, at the end of it, at *d*, about eighteen lines long, is a cylinder of gum lac. It is terminated at *c* by a ball of pith of elder, about two or three lines in diameter, and at *d* by a vertical vane of paper covered with turpentine. A circular band of paper, E F, divided into 360°, is pasted round the cylinder, on a level with the needle, and at the hole, *a*, there is introduced a small cylinder, *a b*, the lower end of which, made of gum lac, carries another ball, *b*, of the pith of elder. The instrument is adjusted when a line passing through the centre of the silver wire, G H, at P, passes also through the centres of the balls *b* and *c*, and points to the centres of the graduated circle, E F.

(57) In this instrument the force of electrical repulsion is balanced against the reactive force of the glass or silver thread, which is twisted more or less from its quiescent position. In using it a charge is communicated to the ball *b*, which is then brought into contact with the ball *c*, mutual repulsion takes place (31), and the needle, *c d*, is turned through a certain arc. By turning however the micrometer button in the direction N P, the wire, G H is twisted and caused to return to its first position and point to the zero of the scale; this being done, it is evident that the force of torsion has been made to balance the repulsive force of the two balls *e c*, and that by comparing the force of torsion, which balanced the repulsive forces at different distances of the balls, measures of the repulsive forces at these distances may be obtained.

The details of an experiment made by Coulomb will serve to illustrate the method of using, and the nature of the indications of this instrument. He communicated an electrical charge to *b*, and having brought it into contact with *c*, the latter was repelled, and finally took up a position at an angle of 36° from *b*, the wire G H had therefore become twisted through an angle of 36°. Coulomb now turned the micrometer button till the distance between the balls was diminished to 18°, but to do this he found that the index M required to be moved over 126° of the graduated circle M N. Now 126° added to 18° (the former torsion) = 144°. The reactive force of torsion at 36° and 18°, is therefore 36 and 144, or in other words, when the distance is diminished *one half* the force had increased *four times*. Again, to maintain the balls at a distance of 8½° apart, the angle of torsion was 575½°, or very nearly 144 × 4, showing that when the distance is diminished *one fourth* (or very nearly so) the force has increased *eight times*. From this and similar experiments at

other distances, Coulomb established the important electrical law, "*that two small spheres, electrified by similar electricities, repel each other with a force inversely proportional to the squares of the distances between their centres.*"

(58) In applying the torsion Electrometer to the determination of the law of the attractive force between two oppositely excited bodies, a slight modification of the apparatus was requisite in order to prevent the balls from rushing into contact, in consequence of the attractive force increasing in a greater ratio than the force of torsion. The difficulty was provided against by extending a thread of fine silk vertically between the top and bottom of the case having its ends attached to them by wax, and allowing the fixed ball to remain in contact with it at the commencement of the experiment. When the two discs are oppositely electrified, the moveable disc is forced from the fixed disc by turning the Micrometer in a direction contrary to that in which it was moved in former experiments. In this way Coulomb obtained results which gave him the same law for electrical attractions as for repulsions, viz. :—that their energy diminished in the same proportion as the *square* of the distance between the electrified bodies was increased.

(59) In consequence of the great care required in manipulating with the torsion balance, and the difficulty of estimating accurately the loss of Electricity in two charged conductors during the performance of an experiment, Coulomb's researches do not appear to have been often repeated, though Biot, Poisson, and other French mathematicians, rest their mathematical theory of Electricity entirely upon them; Faraday however employed this instrument in his investigations into the nature of induction, and he describes (*Ex. Research.* 1180—6) certain precautions needful in its use. In order to ensure uniformity in the inductive action within the cylinder in all positions of the repelled ball, and in all states of the apparatus, he attached two bands of tin-foil, each about an inch wide, to the inner surface of the cylinder, connecting them with each other and with the earth; he also kept a dish of fused potash covered with a fine wire gauze at the bottom of the case, so as to keep the air within in a constant state of dryness. He directs particular attention to the pith-balls, which, even when carefully turned and gilt, are frequently too irregular in form to retain a charge undiminished for a considerable length of time; they should always be examined previous to use, and rejected if they do not hold their charge and become instantly and perfectly discharged by the touch of an uninsulated conductor; and the insulating condition of the instrument, as thus constructed under fair circumstances, is such, that when the balls are electrified so as to give a repulsive torsion force of 400° at a standard distance of 30°, it takes four hours to sink to 50° at the same distance; the average loss from

400° to 300° being at the rate of 2° 7′ per minute; from 300° to 200° of 1° 07′ per minute; from 200° to 100° of 1° 3′ per minute; and from 100° to 50°, to 0° 87′ per minute. Now as a complete measurement by the instrument may be made in much less than a minute, the amount of loss in that time is but small and can easily be taken into account. Faraday thinks that though it requires experience to be understood, the Coulomb balance Electrometer is a very valuable instrument in the hands of those electricians who will take pains by practice and attention to learn the precautions needful in its use.

(60) The truth of Coulomb's law, both in the case of simply electrified conductors, and in bodies upon which given quantities of Electricity have been accumulated, has been confirmed by Sir William Snow Harris, to whom electrical science is indebted for many beautiful discoveries and important practical applications.

The apparatus employed by Sir William in investigating the law of the attractive forces of Electricity accumulated in jars and batteries is shown in Fig. 12, and is thus described by the author (*Phil. Trans.* 1834).

Fig. 12.

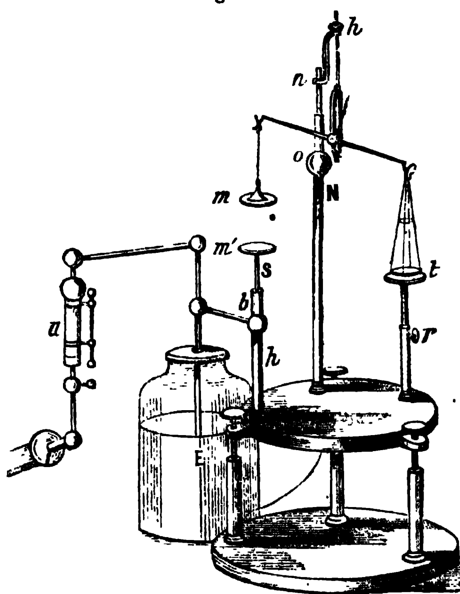


Fig. N represents a simple balance suspended from a curved brass rod *n h*. N can be raised or depressed through small distances by a micrometer screw at *h*, and can be also elevated or depressed by the graduated sliding tube *n o*. The tube *o* is screwed on a brass cap fixed on the glass column N, through the centre of which passes a stout brass wire.

A conducting substance *m*, of any required form, is suspended by a double silver thread from one of the arms of the beam; it is made of light wood, is hollow and gilded. This body is accurately counterpoised by weights placed in the scale pan *t*, suspended from the opposite arm; a similar conductor *m'*, is fixed immediately under the former, and is supported on a graduated sliding tube *s*, insulated on the glass pillar *p*; the pan *t*, when loaded with given weights, rests on a small plate of wood, whose altitude can be easily adjusted by means of the sliding brass rod *r*; the whole is fixed on an elliptical base furnished with three levelling screws.

When the lower conductor, *m'*, is connected with one side of an electrical jar E, through the substance of the ball *b*, and the suspended conductor *m*, with the opposite side, by means of the suspension thread, and the wire passing through the column N, then the attractive force arising from a given accumulation is caused to act immediately between these conductors *m m'*, and may be measured under given conditions by weights placed in the pan *t*.

The distance between the nearest points of the conductors *m m'*, is accurately estimated in the following way. The insulated conductor *m'*, being raised to zero of the graduated tube, so as to touch, or very nearly so, the suspended body *m*, the points of contact are minutely formed by the micrometer screw *h*. The body *m'* is now depressed a given quantity as measured by the divisions on the side, and hence the distance between *m* and *m'* is accurately known; when this distance requires to be greatly increased, it is effected by raising the beam, which is easily done by means of the graduated slide *n o*, but in effecting this it is essential to raise at the same time the pan *t*, so as to preserve the index rod of the beam exactly vertical.

(61) The following experiments made with this instrument show that the laws which obtain in the distribution of Electricity on insulated conductors, obtain likewise in the disposition of given quantities of Electricity on coated jars.

The jar E (Fig. 12) exposing about five square feet of coating, being connected with the unit *u* of measure, the number of charges was noted corresponding to an accumulation, the attractive force of which, operating between the two plane surfaces *m m'*, was equivalent to a force of 4·5 grains. When the quantity of Electricity accumulated was doubled, the force amounted to exactly 18 grains; three times the accumulation balanced a force of 40·5 grains, and so on.

When a second and precisely similar jar was connected with the former, so as to double the extent of coating, similar quantities measured as before only exhibited one fourth of the previous force respectively. With *three* similar jars, that is, with three times the surface, the force was only *one ninth* part of the respective forces first observed. It would seem

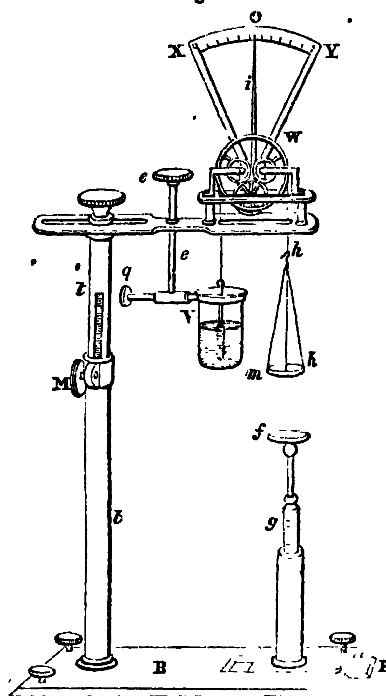
therefore that the force exerted between two given substances is more or less diminished by the presence of a neutral or other body sharing in the attraction, though the physical cause of these effects is not very apparent.

(62) The law according to which the force of electrical attraction varies when exerted between bodies at different distances is arrived at with this instrument without difficulty. The results are of the simplest kind, all the experiments made with it concurring to prove *that the attractive forces vary as the squares of the respective distances inversely, with great precision.* The form of the conductors was found by Harris to have no influence on the results. Two hemispheres attract with precisely the same force as two spheres, and the attractive force between two unequal circular areas was no greater than between two similar areas each equal to the lesser. The attractive force exerted between a charged and a neutral sphere of equal diameter, Harris considers as being made up of a system of parallel forces operating in right lines between the homologous points of the opposed hemispheres.

(63) For measuring directly the attractive force of an electrified body in terms of a known standard weight, estimated in degrees on a graduated arc, Sir William Harris employed an instrument, which he calls the *Hydrostatic Electrometer*, shown in its improved form in Fig. 13 (*Bakerian Lecture, Phil. Trans.*, 1839). The column M, carrying the graduated arc X O Y, and wheel work W, consists of two cylindrical brass tubes, *t t*, about an inch in diameter and 14 inches high, that on which the wheel work is placed moves freely within the other, so as to be readily elevated or depressed, by means of a rack fixed in it and a pinion attached to the upper part of the outer tube at M. The object of this motion is to enable the experimenter to vary the distance between the attracting or repelling discs *m*, *f*, without disturbing the lower disc *f*, or otherwise to adjust the same distance by changing the position of both the discs, manipulations which greatly simplify many intricate cases of experiment. In order to estimate the distances when the position of the disc *m* is varied, a graduated sliding piece *t*, about three inches long, is placed upon the inner tube free from the rack work, and being moveable upon it with friction may be set with any required altitude of the whole column M to zero of its scale. In this way all subsequent changes of distance produced by elevating or depressing the interior tube *t* are easily known.

Changes of distance attendant on the motion of the lower disc *f* are estimated by the graduated slide *g*, the fixed tube of which is attached to a foot-piece P moveable in a bevelled groove on the base B, the whole may be hence withdrawn for a certain distance if required, so as to place the disc *f* without the influence of the upper disc *m*.

Fig. 18.



The disc *m* is suspended from the fine silver thread passing over the balanced wheel W by three threads of varnished silk, after the manner of a common scale pan, so as to insulate it if requisite; it is connected with the ground in ordinary cases by a fine wire terminating in a small hook loosely hung from the silver thread to the surface of the disc *h*, *h*. The centre of the wheel W is accurately placed in the centre of the arc X, Y, which with its radii of support is made of varnished wood, the graduated scale being of card, wood, or ivory. The arc is the sixth part of a circle divided into 120 parts, 60 in the direction O X, and 60 in the direction O Y, the centre O being marked zero. The extremities of the axis of the wheel W are turned to extremely fine points; and rest on two large friction wheels. The index *i* is a light straw attached to the extremity of a small steel needle, inserted diametrically through the circumference, which indicates on the graduated arc X Y, the force exerted between the conductors *m f*. The disc *m* is counterpoised by a short cylinder of wood suspended in a similar manner from the opposite side of the wheel by means of a silk thread, and resting partly in water contained in the glass vessel V, which is supported in a ring of brass moveable in a brass tube attached to a sliding rod *q*. This rod is acted

on by a nut and screw enclosed in a cylindrical piece *e*, fixed to the horizontal plate carrying the wheel work. Hence the water vessel may be elevated or depressed at pleasure, and the index *i* readily adjusted to zero or any other required point on the arc. The gravity of the suspended disc *m* being opposed by that of the counterpoise, it may be so far considered as existing in free space devoid of weight, and will therefore become very readily moved by every new force applied to it.

It may consequently be caused to approach to, or recede from, the fixed conductor *f*, by the operation of forces acting in either of these directions: the motion will however be speedily arrested by the cylindrical counterpoise, which, becoming either further immersed in, or otherwise raised in the water, furnishes, in the greater or less quantity of water displaced, a measure of the force. In this way, the force may be estimated either in degrees, or in grains of actual weight (since the number of grains requisite to be added to either side, in order to advance the index in either direction a given number of divisions, may be immediately found by experiment), which, as the sections of the cylinder are all similar, will be found to increase or decrease with the degrees of the arc. Thus if one grain advance the index in either direction five degrees, then two grains will advance it ten degrees, and so on.

(64) These arrangements enable us to operate with the instrument in the following way. Let it, for example, be required to estimate the attractive force between the plates *m*. *f*, at any given distance D, suppose ·6 of an inch. We first bring the discs into contact as nearly as may be, and then set the graduated slider *t* at zero of its scale, by bringing it to coincide with the upper edge of the outer tube M. Then (having also set the slider supporting the insulated disc *f* at zero) we either raise the tube *t*, ·6 of an inch, or depress the slide *g*, by the same quantity, or otherwise raise the upper and depress the lower disc by quantities making together ·6 of an inch. In either case the discs will finally be ·6 of an inch apart, measured between the opposed surfaces previously in contact. Under these conditions let either plate be taken, insulated, and charged, whilst the other is neutral and free. Suppose the lower disc *f* to be charged with a given quantity, and the suspended disc *m* free, then the attractive force which ensues will cause the index to advance in the direction O Y, a given number of degrees; consequently the distance between the plates *m f* will be diminished. Let the index be now brought again to zero, by turning the milled head of the screw *e* so as to depress the water vessel V, then the force whatever it may be is acting between the plates at ·6 of an inch. To discover the amount of this in degrees, discharge effectually the air and opposed plates *m f*. by touching them simultaneously with a bent wire, the force then vanishes and the index declines in the direction O X. The amount of this

declination is evidently the force in degrees at a given distance D, =·6 of an inch.

Experiments with this instrument are remarkably clear considering the subtile character of the principle to be investigated; though it is not available for the measurement of such minute forces as those applicable to the balance of Coulomb; its indications depending on the force between two opposed planes operating on each other under given conditions, are reducible to simple laws, and are hence invariable and certain. The attractive force between the discs is not subject to any oblique action, is referable to any given distance, and may be estimated in terms of a known standard weight.

(65) Sir W. Harris's experiments on electrical attraction made with his instruments led him to the following results.

1°. That the forces between two spheres will be inversely as the distances between their nearest points multiplied into the distances between their centres.

2°. That two spheres at the distances of 2·2, 2·5, 2·8, and 3·0 inches, exert the same force as two circular plates at the distances of 0·661, 1·117, 1·496, and 1·732 inches respectively.

3°. That the attractive force of two opposed conductors is not influenced by the form or disposition of the unopposed portions. The attractive force, for example, is the same whether the opposed bodies are merely circular planes, or planes backed by hemispheres or cones. Two hemispheres also attract each other with the same force as the spheres of which they are hemispheres.

4°. The force between two opposed bodies is directly as the number of attracting points, the distance being the same. Thus two circular planes of unequal diameter do not attract each other with a greater force than that of two similar areas, each equal to the lesser. In like manner the attractive force between a ring and a circular area of the same diameter is equal to that exerted between two similar rings each equal to the former.

5°. The attractive force between a spherical segment and an opposed plane of the same curvature, is equal to that of two similar segments on each other.

(66) For the measurement of small forces of repulsion, Harris employed a new arrangement of the balance of torsion (*Phil. Trans.*, 1836), which, from the peculiar mechanical principle on which it depends he calls "*the Bifilar Balance.*" The reactive force in this instrument is not derived from any principle of elasticity as in Coulomb's, but is altogether dependent on gravity. It is obtained by means of a lever at the extremity of two parallel and vertical threads of unspun silk, suspended within a quarter of an inch of each other from a fixed point. The threads are stretched more or less by a small weight, and the

repulsive force is caused to operate much in the same way as in Coulomb's balance of torsion. As the threads tend to turn as it were upon each other, the stretching weight becomes raised by a small quantity, and thus gravity is brought to react against the repulsive force in operation. The delicacy of this balance is extremely great, and will render sensible a force of the $\frac{1}{50000}$th part of a grain.

(67) Harris's experiments on the relation of the repulsive force to the quantity of Electricity led him to the following results:—The discs being charged *equally* and to a given intensity, the forces vary in an inverse ratio of the squares of the respective distances; when however the quantity on one of the discs is diminished, that is, when they are charged unequally, this law is only apparent up to a certain limit; sometimes at certain distances, the law is in an inverse ratio of the simple distance, or nearly approaching to it; while within certain limits, and at other distances, the law of the force becomes irregular, until at last the repulsion vanishes altogether and is superseded by attraction, being apparently disturbed by some foreign influence.

The quantities of Electricity contained in either of the repelling bodies are not always proportional to the repulsive forces, a result which, though apparently anomalous and unsatisfactory, Sir William believes to be in accordance with the general laws of electrical action: the force of *induction* (72) for example, not being confined to a charged and neutral body, but operating more or less freely between bodies similarly charged, it is evident that the inductive process between bodies similarly charged may become indefinitely modified by the various circumstances of quantity, intensity, distance, &c., giving rise to apparently complicated phenomena.

(68) Harris proved that a *spherical* conductor, either hollow or solid, and *a plate of equal area*, have the same electrical capacity, a conclusion not opposed to the experiments of Coulomb. This philosopher found that the balls of his balance (56) were repelled with only *half the force* at a given distance, when the quantity of Electricity in one of them was reduced to one half, and he further concludes that the whole repulsive force expressed by $\frac{F}{D^2}$ diminishes for the same distance D as the absolute quantity of Electricity in each of the repelling bodies considered as points. This principle he applies extensively, with the view of detecting the ratios of the quantities of Electricity accumulated in charged bodies, or in any given point of them. The Electricity of the given point he considers as transferable to a small insulated disc, first applied to the body and subsequently placed in his balance, the ball of the needle being already charged with a certain quantity of the same Electricity. The insulated disc is called a *proof plane;* when this plane is placed upon any part of a charged body it is supposed

to be identical with an element of the surface, so far as relates to the distribution of the accumulated Electricity, and hence, on removing it to the balance, it is assumed to operate just as the element would do under similar circumstances. Harris, however, considers it doubtful whether any indefinitely thin carrier plate can be altogether considered as an element of the surface of an electrified body to which it is applied. He has shown, moreover, that the respective quantities of Electricity are not always as the repulsive forces, and if so, the indications of Coulomb's instrument may not in all cases be directly proportionate to the quantity of Electricity in the proof plane.

(69) According to Coulomb, the relative electrical capacities of a solid or hollow sphere and a circular plate of equal area, are as two to one; that when Electricity is accumulated on a globe, either hollow or solid, it is only found upon the exterior surface, hence, in expanding the globe into a plane circular area of the same superficial extent, each side to each side, we double its capacity by giving it another exterior surface; twice the quantity of Electricity may, therefore, now be placed on it under the same intensity. Now, if this view be correct, by substituting, for the circular plate, a second sphere, whose exterior surface is equal to the *two surfaces* of the plate, the result would be the same as before. Harris found, however, that the electrical re-actions after the respective contacts with the plate and sphere, the areas of which were equal, instead of being as two is to one, according to Coulomb's theory, are nearly the same, and he hence concludes that the result arrived at by Coulomb's method of experiment may be classed with those cases in which the repulsive force exercised by the balance is not proportionate to the quantity of Electricity, and he gives further experiments which verify the results at which he formerly arrived, viz.,—"That the capacity of a sphere is the same as that of a circular plane of equal area, into which we may suppose it to be expanded;" and, "that a spherical conductor, either hollow or solid, and a plate of equal area, have the same electrical capacity," a conclusion not opposed to Coulomb's own experiments. Lastly, from an experimental examination of the indications of the proof plane, Sir William has come to the conclusion that the quantity of Electricity taken from the surface of a charged body by a small insulated disc of considerable thickness, may be greatly influenced by the position of the point of application, *independently* of the quantity of Electricity; so that the same quantity may possibly exist in two different points and yet the proof plane become charged in a different ratio, the inductive power of the plate being different in these points.

CHAPTER III.

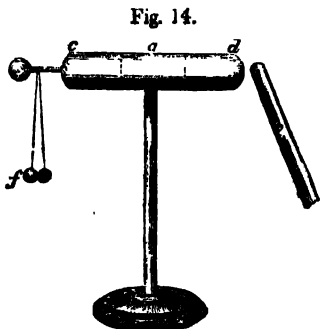
Induction—Distribution—Condensers and Multipliers.

(70) *Induction.*—Amongst the earliest manifestations of the phenomena of Electricity, effects were rendered apparent which proved that contact between two bodies was not absolutely requisite to cause them to assume the electrical state; but, on the contrary, it was found that the force or agency operates at a distance, producing distinct mechanical effects. Thus an electrified body, or an excited rod of glass, or sealing-wax, when brought near to bits of paper, feathers, or other light substances, causes them to move towards it, and if presented to a small suspended unelectrified ball, it draws it aside from the vertical position.

Supposing a pith-ball to be insulated by a filament of silk and electrified, we know by experience that if another similar but unelectrified pith-ball be brought near, an attractive force will be exhibited; but if it be true that there exists no attraction between the Electricity diffused on the pith-ball and the matter of the pith, how can it be imagined that there should exist any attraction between it and the other pith-ball? But yet the attractive effects are certain; how, then, are they to be explained?

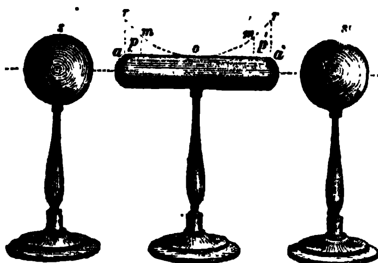
(71) Let us first examine the condition of fixed bodies:—Let *d a c*, Fig. 14, be a conducting body, such as a cylinder of brass, supported on a glass stand, and furnished with a pith-ball Electroscope, and let *e* be an excited glass tube. On approaching this tube within about six inches distant from *d*, the pith-balls will instantly separate, indicating the presence of free Electricity. Now, in this case the electric *e* has not been brought sufficiently near to the conducting body to communicate to it a portion of Electricity, and the moment that it is removed to a considerable distance the balls fall together, and appear unelectrified;

Fig. 14.



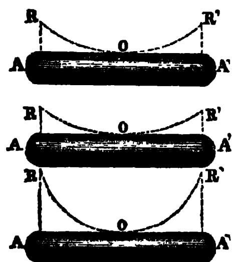
on approaching *e* to *d* the balls again diverge, and so on. The fact is, this is a case of what is termed *induction*, the positive Electricity of *e* decomposes the neutral and latent combination in *d a c*, attracting the negative towards *d*, and repelling the positive towards *e*, and the balls consequently diverge, being positively electrified. On removing *e* the force which separated the two Electricities in *d a c* is removed, the separated elements re-unite, neutrality is restored, and the pith-balls fall together. The Electricity of *e induces* a change in the electric state of *d c*.

Fig. 15.



In Fig. 15, suppose *s s'* to be two metallic insulated spheres, and *a a'* an insulated metallic conductor; suppose *s* to be strongly charged with positive, and *s'* with negative Electricity, and placed in the position represented in the figure. If *a a'* be examined by means of an Electrometer, it will be found that the only part which is free from Electricity is the centre *o*, that half of the conductor extending from *o* to *a* is electrified negatively, and that half extending from *o* to *a'* is electrified positively. The intensities of the opposite electricities at the extremities will be found to be equal, and at any points equally distant from the centre, as *p p'*, the depths of the electric fluid will be equal, and the electric state of each half may be correctly represented by the ordinates *p m*, *p' m'* of two branches of a curve which are precisely similar and equal.

Fig. 16.

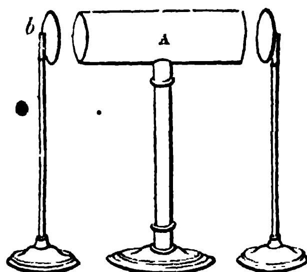


In Fig. 16, suppose A A' to be a conductor, and the curves of the circles R R' those branches the ordinates of which represent the densities of the Electricity induced upon it by the spheres *s s'* (Fig. 15); by gradually removing these in an equal manner, the curves will become less and less concave, and the ordinates correctly represent the diminished density. But if the spheres be made to approach the conductor, the accumulation of Electricity towards the extremities will be increased, and the curve representing the electrical densities will take the form shown in the lower figure.

These results strongly favour the idea of the existence of two electric fluids, uniformly distributed in equal proportions over a body in its natural state, and the conductor comports itself exactly as it theoretically should do when charged with equal quantities of the contrary electricities.

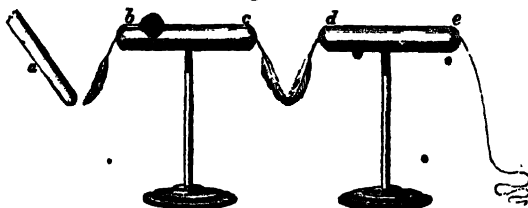
(72) We have seen that a rod of excited glass, when approached to one extremity of an insulated conductor, causes the pith-balls, suspended from the other end, to diverge. Now, on examining the conductor, it is found that the end nearest the positively excited electric has become *negative*, and the opposite end *positive*, while an intermediate zone is neutral and unelectrified. An examination of the electrical condition of a conductor while under the influence of induction, may be made in an easy and satisfactory manner by the apparatus shown in Fig. 17.

Fig. 17.



Let A be a cylindrical conductor five or six inches long and about three inches in diameter, and let *b* and *c* be two thin metallic discs, each insulated and of such a size as to fit accurately the ends of the conductor, so that, when in their places, the whole system may represent one conducting surface. Now, having given a metallic ball a charge of positive Electricity, suspend it by a silk thread, at a distance of about two inches from the cylinder. Next remove the disc, *b*, by its insulating handle, and test its electrical condition, it will be found to be *negative;* then remove and examine *c*, it will be

Fig. 18.

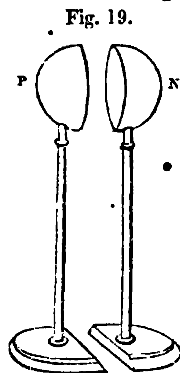


found to be positive. Again, let two metallic cylinders, *b c*, *d e*, Fig. 18, be placed within an inch or more of each other in a right line; *b c* must be insulated, but the end *e* of *d e* may be connected with the earth by a wire; let feathers or light pith-balls be suspended by linen threads from *b c* and *d;* on now bringing an excited glass tube,

a, within three or four inches of *b c*, the feather or ball hanging from *b* will be attracted, at the same time those suspended from *c* and *d* will rush together.

Let P N, Fig. 19, be two hemispheres of wood, covered with tin-foil, mounted on rods of varnished glass, and standing on wooden feet, so that they may be placed in contact with each other, as shown in Fig. 19; while thus in contact approach them with an excited glass rod, and then remove it, the hemispheres will not be found to have acquired any electrical charge. Now vary the experiment by separating the two hemispheres; while under the influence of the excited electric, and on examining them by the Electroscope, Fig. 8, each will be found electrified, that nearest the glass rod with negative, and the other with positive Electricity. It is scarcely necessary to say that in the separation of the hemispheres from each other, care must be taken to preserve their insulated condition.

Fig. 19.



(73) By the following striking experiment the operation of the electric force at a distance may be made manifest in a large room. Arrange a long insulated cylindrical conductor, with one extremity about a quarter of an inch from a jet from which a gentle stream of gas is escaping, approach suddenly towards the other end a well-excited glass tube, the gas will seldom fail to become inflamed; whilst the excited tube is still in the immediate vicinity of the conductor extinguish the flame, then suddenly withdraw the tube, and the gas will generally be re-inflamed.

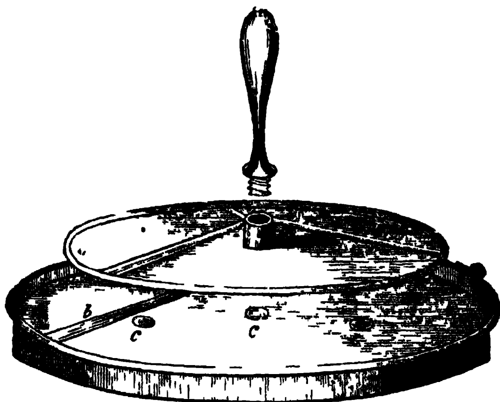
(74) From these experiments it appears that the electrical disturbance of a neutral body by the proximity of an electrified body is only of a temporary nature, all signs of excitement disappear immediately the charged body is removed. Let us, however, introduce a little variation into the conditions of the experiments. Whilst the conductor, Fig. 14, is under the influence of the excited glass, let it be touched with the finger, the pith-balls will instantly collapse, because the positive Electricity with which they were divergent has acquired through the finger, from the earth, a corresponding supply of negative Electricity; the *natural* negative Electricity, however, of the conductor is still retained at the opposite extremity by the attractive influence of the glass. On now removing, first the finger, and then the glass tube, the pith-balls will again open, *and will remain divergent*, because the natural negative Electricity of the conductor being relieved from the inducing influence of the glass tube, will now become expanded over the whole conductor—the pith-balls are now diverging with *negative* Electricity.

(75) It is precisely in this way that we communicate a permanent charge to the gold leaf Electroscope.

If a *positive* charge is required, an excited stick of wax is approached to the cap of the instrument, which is then touched with the finger; again insulated, and the wax immediately removed. To communicate a *negative* charge, an excited tube of glass is substituted for the wax, and the manipulations are the same as before. The instrument with Singer's improvement, Fig. 8, will, when dry and warm, retain a charge thus given to it for several hours, but certain precautions necessary to be observed in interpreting its indications are thus described by Faraday (*Chem. Manip.*, p. 437) :—"Suppose it is desired to ascertain the kind of Electricity by which the leaves of the Electroscope are diverged, we may employ either a stick of excited wax or a tube of excited glass; the divergence will *increase* if due to Electricity of the same kind as that of the electric approached, but will *diminish* if of the opposite kind; but in applying these excited rods some precaution is required. They must be excited at such a distance from the instrument as to have no influence over it, and their effect on the leaves watched as they are gradually approached towards the cap. It is the *first* effect that indicates the kind of Electricity in the instrument, and not any stronger one, for, although if the repulsion be increased from the first no nearer approach will cause a collapse to take place, except the actual discharge of the leaves against the sides of the glass; yet where *collapse* is the first effect it may soon be completed, and repulsion afterwards occasioned from a too near approach of the strongly excited tube. It is, therefore, the first visible effect that occurs as the test rod is made to approach from a distance, that indicates the nature of the Electricity; and when this effect is observed, the rod should not be brought nearer, so as permanently to disturb the state of the Electroscope, but should be removed to a distance, and again approached for the purpose of repeating and verifying the preceding observation. The instrument will thus undergo no permanent change in its Electricity, remaining, after a good experiment, in the same state as at first."

(76) A very instructive and useful instrument, depending on inductive action, is the Electrophorus, Fig. 20. It consists of three parts—a cake of resinous matter, composed of shell-lac, ten parts; common resin, three parts; white wax, two parts; Venice turpentine, two parts; pitch, half a part; or, as Pfaff recommends, resin, eight parts; gum lac, one part; Venice turpentine, one part; the materials are melted at a gentle heat; a conducting plate or *sole*, which is a circular metallic plate with a rim about a quarter of an inch deep round the edge, into which the composition is poured, and a cover which is of metal, provided with a glass handle.

Fig 20.



To use it, the resinous plate is excited by holding it in the hand in a slanting direction, and striking it briskly several times with a piece of dry warm fur or flannel, or with a warm silk handkerchief; the cover is then laid on, and on removing it by its insulating handle, it is found to have acquired a feeble charge of *negative* Electricity by the contact. Let the metallic plate be re-placed, and *uninsulated* by touching it with the finger, and on again lifting it by its handle, it will be found to give a strong spark of *positive* Electricity. The process may be repeated an unlimited number of times without any fresh excitation of the plate being required, and indeed after being once excited, a spark may be obtained from it during many weeks, if kept in a dry place, since the resin acts solely by its inductive influence on the combined Electricities actually present in the plate.

(77) It will not be difficult at once to comprehend this. When the metallic plate is placed on the excited resin, its contact with it is, on account of the inequalities on the surface of the latter, very imperfect. It is therefore in a condition analogous to that of a conductor, under the influence of an electrified surface, its lower surface becoming *positive*, and its upper surface *negative*, by induction. When it is removed from the resin the separated Electricities re-unite; but when the plate is uninsulated, while in contact with the resin, the repelled negative Electricity is neutralised by a corresponding quantity of positive Electricity from the earth, and the plate becomes positively charged. It is thus clear that the Electricity of the moveable plate is derived not in the way of *charge* from the resin, but is the result of the process of induction.

The figure represents Mr. John Phillips's modification of the Electrophorus, the object of which is to avoid the trouble and tediousness of

establishing a communication between the insulated cover and the earth, by means of the finger, when electrical accumulation, or sparks in rapid succession, is the object. Three methods are proposed: the first consists in raising from the metallic basis above the edge of the resin, a brass ball and wire, to which the edge of the cover, or a brass ball upon it, may be applied; this method is stated to act very well, especially with small covers, which can with ease and certainty be directed to any particular point of the sole. The second is to fix a narrow slip of tin-foil *b*, quite across the surface of the resinous plate, and unite it at each end with the metallic basis. This construction answers perfectly and instantaneously, and is very convenient with large circles, the covers of which, though uneven, will then be sure to touch some conducting point. The third method is to perforate the resinous plate quite through to the metallic basis, at the centre, and any other points, and at all those points to insert brass wires, *c*, *c*, *c*, with their tops level with the resin. The latter of these methods is preferred, and Mr. Phillips describes an instrument constructed on this principle, with a cast-iron basis 20·5 inches in diameter, resinous surface 19·75 inches, and cover 16·25 inches, which yields loud and flashing sparks two inches long, and speedily charges considerable jars. The cover can be easily charged from fifty to one hundred times in a minute by merely setting it down and lifting it up, as fast as the operator chooses, or as the hand can work. In charging a jar or plate, one knob of the connecting rod is placed near the insulated surface of the jar, and the other some inches above the cover, which is alternately lifted up and set down, and the jar is thus very quickly charged.

A very useful modification of the Electrophorus of Volta is made by coating a thin pane of glass on one side with tin-foil to within about two inches of the edge, placing it with the coated side on the table; the other side is to be excited by friction by a piece of silk covered with amalgam, then carefully lifting the glass by one corner, place it on a badly conducting surface, as a smooth table, or the cover of a book, with the *uncoated side downwards* Touch the tin-foil with the finger, then carefully elevate the plate with one corner, and a vivid spark will dart from the coating to any conducting body near it: re-place the plate, touch it, again elevate it, and a second spark will be produced. By this means an electric Leyden jar may speedily be charged. This modification of the Electrophorus, or *Electrolasmus*, as it is called by its inventor, Dr. Golding Bird, is a very useful instrument in the chemical laboratory.

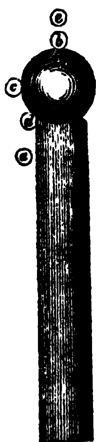
(78) It was by an apparatus constructed on the principles of the Electrophorus that Faraday succeeded in demonstrating that *induction is essentially a physical action, occurring between contiguous*

particles, never taking place at a distance without polarizing the molecules of the intervening dielectric.

When an excited glass tube is brought near an insulated conductor in which the electric equilibrium is shown to be disturbed by the divergence of pith-balls, we are not to suppose that the disturbance is occasioned by an action at a distance: for it has been shown by Faraday that the intervening dielectric *air* has its particles arranged in a manner analogous to those of the conductor, by the inducing influence of the glass tube. The theory of induction depending upon an action between contiguous molecules, is supported by the fact which would otherwise be totally inexplicable, that a slender rod of glass or resin, when excited by friction and placed in contact with an insulated sphere of metal, is capable of decomposing the Electricity of the latter by induction most completely, even at the point of the ball equi-distant from the rod, and consequently, incapable of being connected with it in a right line: so that it must either be concluded that induction is exerted in *curved lines*, or propagated through the intervention of contiguous particles. Now as no radiant simple force can act in curved lines, except under the coercing influence of a second force, we are almost compelled to adopt the view of induction acting through the medium of contiguous particles.

The apparatus employed by Faraday is shown in Figs. 21 and 22. It consists of a shell-lac Electrophorus, on the top of which is placed a brass ball; the charge on the surface of which is examined by the carrier ball of Coulomb's Electrometer (56). It was always found to be positive. When contact was made at the under part of the ball, as at (*d*) Fig. 21, the measured degree of force was 512°; when in a line with its equator, as at (*c*), 270°; and when at the top of the ball, as at (*b*), 130°. Now, the two first charges are of such a nature as might be expected from an inductive action in straight lines; but the last is clearly an action of *induction in a curved line*, for during no part of the process could the carrier ball be connected in a straight line with any part of the inducing shell-lac. Indeed, when the carrier ball was placed by Faraday not in contact with the inducteous body at all, as at (*e*), it was found to be charged to a higher degree than when it had been in contact; and at (*a*) it was affected in the highest degree, having a result above 1000°.

Fig. 21.



When a disc or hemisphere of metal was employed, as in Fig. 22, no charge could be given to the carrier when placed on its centre; but when placed considerably above the same spot, a charge was obtained, and this even when a *thin film of gold leaf* was employed;

at (*i*) the force was 112°, at (*k*) 108°, at (*l*) 65°, at (*m*) 35°; the inductive force gradually diminishing to this point. But on raising the carrier to (*n*), the charge increased to 87°; and on raising it still higher, to (*o*), it still further increased to 105°. At a higher point still (*p*), the charge decreased to 98°, and continued to diminish for more elevated positions.

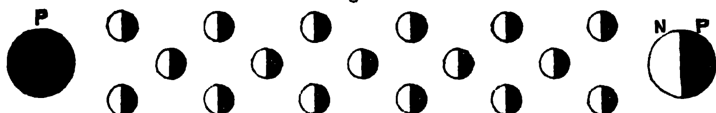
Fig. 22.



(79) On reflecting upon these beautiful experimental results, it seems impossible to resist the conclusion that induction is not through the metal, but through the air, in curved lines, and that it is an action of the contiguous particles of the insulating body thrown into a state of polarity and tension, and capable of communicating their forces in all directions.

We must, in consequence of these decisive experiments, therefore, take a new view of the electric force, and instead of considering the electric fluid to be confined to the surfaces of the bodies by the mechanical pressure of the non-conducting air, which was the opinion previously entertained, we must consider the force originating or appearing at a certain place to be propagated to, and sustained at, a distance, through the intervention of the contiguous particles of the air, each of which becomes *polarized*, as in the case of insulating conducting masses, and appears in the inducteous body as a force of the same kind, exactly equal in amount, but opposite in its direction and tendencies. Thus, suppose P, Fig. 23, to be a positively charged

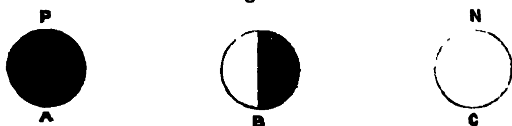
Fig. 23.



body, and N P a previously neutral body at a distance, the action at P is transferred to N P, through the medium of intervening molecules, each of which becomes electro-polar, or disposed in an alternate series of positive and negative poles, as indicated by the series of black and white hemispheres.

Again, let three insulated metallic spheres, A, B, C, be placed in a line,

Fig. 24.



and not in contact; let A be electrified positively, and then C uninsulated; under these circumstances B will acquire the negative state at the surface

towards A, and the positive state at the surface furthest from it, and C will be charged negatively. The ball B will be in what is called a polarized condition, *i. e.*, its opposite parts will exhibit the opposite electrical states, and the two sums of these opposite states will be exactly equal to each other. A and C will not be in this polarized state, for they will be, as it is said, charged, the one positively and the other negatively.

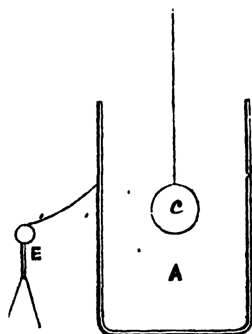
(80) The mechanism of inductive action, and the practical demonstration of the fact, that it is from molecule to molecule of any substance, gaseous or solid, that the decomposition of the natural Electricities alone can take place, may be beautifully shown by plunging in a vessel of oil of turpentine (which is an excellent fluid insulator), two brass balls, of which one is in connexion with an electrical machine and the other with the ground. On turning the machine, the latter becomes excited by induction. If now a number of short shreds of sewing silk be mixed with the oil of turpentine, the mechanism of the inductive action is shown by the little bits of silk attaching themselves mutually by their extremities, by which they transmit the Electricity of the machine, by a series of decompositions, to the ball which is connected with the ground. If the excitation be very violent, the attractions and repulsions become too strong to be regularly transmitted, and this induction is accompanied by a powerful current of the particles of the oil from the first ball to the second. The particles immediately in contact with the directly excited ball acquire its state, and being repelled, immediately pass off to that which has obtained by induction the opposite condition, and those become neutralized. Now what here occurs with the oil of turpentine takes place in ordinary induction with the air; every molecule of it interposed between the solid bodies becomes itself subjected to the inductive action, and forms a chain of alternate positive and negative poles, by which the effect may be transmitted to any distance. If the excitation be very great, the neutralization may occur with violence and rapidity, and generate currents as in the oil of turpentine. It is these currents which, being produced by the repulsion of the particles of air from excited points, are rendered sensible in the effect termed the *electrical aura*, and are shown by the experiment of revolving flies.

(81) The following experiments have been also adduced by Faraday (*London and Edinburgh Phil. Mag.*, 1843, vol. xxii.), as giving a very precise and decided idea to the mind respecting certain principles of inductive electrical action, and as the expression and proof of certain parts of his view.

Let A, Fig. 25, represent an insulated pewter ice-pail, ten and a half inches high and seven inches in diameter, connected by a wire with a delicate gold leaf Electroscope, E, and let C be a round brass ball, insulated

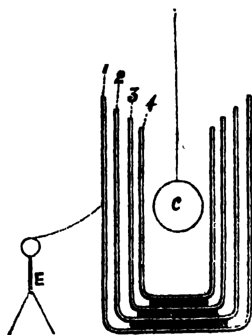
by a long dry thread of white silk; let this ball be charged positively, and introduced into A, as shown in the figure; the Electroscope, E, will immediately diverge also with positive Electricity; on removing C the leaves of the Electroscope will collapse. As C enters A the divergence of E will increase, until C is about three inches below the edge of the vessel, and will remain quite steady and unchanged for any greater depression. This shows that at that distance the inductive action of C is entirely exerted upon the interior of A, and not in any degree directly upon external objects. If C be made to touch the bottom of A, *all* its charge is communicated to A. There is no longer any inductive action between C and A, and C, upon being withdrawn and examined, is found perfectly discharged. If C be merely suspended in A it acts upon it by induction, evolving Electricity of its own kind on the outside of A; but if C touch A its Electricity is then communicated to it, and the Electricity that is afterwards upon the outside of A may be considered as that which was originally upon the ball C: as this change, however, produces no effect upon the leaves of the Electroscope, it proves that the Electricity *in* C and that *induced* by C are accurately equal in amount and power.

Fig. 25.



Again, four ice-pails, each insulated by standing on a plate of lac, may be placed one within the other, as shown in Fig. 26. With this system the ball, C, acts precisely as with a single vessel, so that the intervention of many conducting plates causes no difference in the amount of inductive effect. If C touch the inside of 4 the leaves are still unchanged. If 4 be removed by a silk thread, the leaves perfectly collapse; if it be introduced again, they open out to the same extent as before. If 4 and 3 be connected by a wire, let down between them by a silk thread, the leaves remain the same, and so they still remain if 3 and 2 be connected by a similar wire; yet all the Electricity originally on the carrier, and acting at a considerable distance, is now on the outside of 2, and acting through only a small non-conducting space. If at last it be connected with the outside of 1, still the leaves remain unchanged. If in the place of the

Fig. 26.



metallic vessels a thick vessel of shell-lac or sulphur be introduced, not the slightest change in the divergence of the leaves of the Electroscope is produced. "Hence," says Faraday, "if a body be charged, whether it be a particle or a mass, there is nothing about its action which can at all consist with the idea of exaltation or extinction: the amount of force is perfectly definite and unchangeable; or to those who in their minds represent the idea of the electric force by a fluid, there ought to be no notion of the compression or condensation of the fluid within itself, or of its coercibility, as some understand that phrase. The only mode of affecting this force is by connecting it with force of the same kind, either in the same or the contrary direction. If we oppose to it force of the contrary kind, we may, *by discharge*, neutralize the original force, or we may, *without discharge*, connect them by the simple laws and principles of static induction; but away from induction, which is *always of the same kind*, there is no other state of the power in a charged body, that is, there is no state of static electric force corresponding to the terms of *simulated*, or *disguised*, or *latent* Electricity, away from the ordinary principles of inductive action: nor is there any case where the Electricity is *more latent* or *more disguised* than when it exists upon the charged conductor of an electrical machine, and is ready to give a powerful spark to any body brought near it."

(82) Thus there is hardly any electric phenomenon in which inductive action does not come into play. When light substances are attracted by excited glass or wax, it is in consequence of the disturbance of their natural electrical states: in the one case, the positive fluid being repelled and the negative attracted, and in the other, the negative fluid being repelled and the positive attracted. The following experiment illustrates this development of Electricity by induction in an interesting manner. Support a pane of dry and warm window glass, about an inch from the table, by means of blocks of wood or two books, and place beneath it several pieces of paper or pith-balls. Excite the upper surface by friction with a silk handkerchief, the Electricity of the glass becomes decomposed, its negative fluid adhering to the silk, and its positive to the upper surface of the glass plate. This, by induction, acts upon the lower surface of the glass, repelling its positive Electricity, and attracting its negative. The lower surface of the glass thus becoming virtually electrified by induction through its substance, attracts and repels alternately the light bodies placed beneath it, in a similar manner with the excited tube. The state of a body when under the influence of a distant electric is called *induced Electricity*. The originally active body is called the *inductric*, and that under its influence the *inducteous*; thus, in the last figure, A is the *inductric* and C the *inducteous* body, the electrical state of the

latter being sustained through the intervention of the intermediate and polarized ball, B. "All charge," says Faraday (*Ex. Research.*, series xi., p. 1178), "is sustained by induction. All phenomena of intensity include the principle of induction. All *excitation* is dependent on, or directly related to, induction. INDUCTION appears to be the essential function, both in the first development and the consequent phenomena of Electricity."

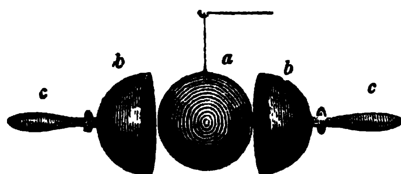
(83) But Faraday's theory of induction does not rely on the polarization of *matter* in the ordinary acceptation of that term. It contemplates something much more refined, dealing rather with the *powers* or *forces* which in the generally received view of the atomic constitution of matter are associated with the material atom, giving to it its characteristic effects and properties. Indeed he sees a difficulty in reconciling that view of the nature of matter, according to which it consists of little impenetrable nuclei of solidity with superadded powers, with certain facts connected with electrical conduction. According to this view the particles of matter do not actually touch each other, the only thing in a mass of gross matter which is continuous being *space*, and this must be considered as permeating it in every direction, like a net. Thus, taking the cases of a conductor of Electricity, a metal for instance, and a non-conductor of Electricity, as a piece of shell-lac, we are compelled to admit that space is both a conductor and an insulator, a conclusion which Faraday thinks must falsify the ground of reasoning which tends to it, and he perceives great contradictions in the general conclusions which flow from the view that matter is composed of atoms more or less apart from each other, with intervening spaces. He is disposed rather to adopt the theory of Boscovich, according to which atoms are mere centres of forces or powers, not particles of matter in which the powers themselves reside; and if we take such atoms to be indefinitely small, then the particle of matter away from the powers becomes a mere mathematical point, may vanish altogether, and the powers or forces constitute the substance; and these powers or forces may be conceived to pervade all space, and to penetrate everything we call matter. It may be difficult at first to think of the powers of matter, independent of a separate something to be called *the matter*; but it is more difficult, and indeed impossible, to think of or to imagine that *matter* is independent of the *powers*; the powers we know and recognise in every phenomenon of the creation, the abstract matter in none. Faraday's theory of induction is therefore limited to mere powers or forces, and particles of common matter taken as centres of force are more or less conducting. A particle in its quiescent state is not polar as represented in B, Fig. 24, but under the influence of other charged particles it becomes so; it is then in a forced or constrained condition. When

this forced or polar condition is readily assumed it is readily destroyed, and *conduction* is the result; when the contiguous particles communicate their forces less readily, *insulation*, more or less perfect, is the consequence; and the action of a charged body on insulating matter is *induction*.

(84) *Distribution of Electricity.*—When a body receives a charge of Electricity the charge does not, as in the case of heat, diffuse itself throughout the whole of its substance, but is confined entirely to its surface; from this it follows that a ball formed of any material will be equally electrified whether it be solid or hollow, and, if it be hollow, the amount of Electricity will be the same, whether the shell of matter of which it is formed be thick or thin.

To demonstrate practically the distribution of Electricity on the surface of a conductor, the following apparatus was contrived by Biot.

Fig. 27.



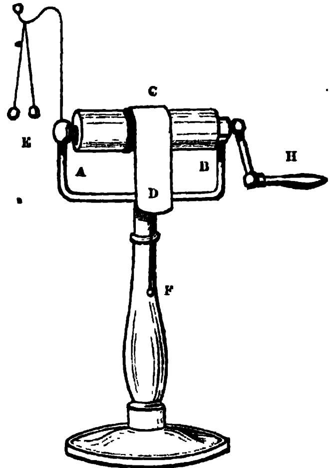
A sphere of conducting matter *a*, is insulated by a silk thread, and two thin hollow covers *b b*, made of gilt paper or tin, thin paper or copper, are provided with glass handles *c c*, and correspond with the shape and magnitude of the conductor. The sphere *a* is electrified, and the covers are then applied, being held by the glass handles. After withdrawing them from *a*, they are found to be charged with the same kind of Electricity as was communicated to *a*, which will be found to have lost the *whole of its charge*, proving that it resided on the surface only.

This experiment will not succeed unless the covers be withdrawn rapidly and simultaneously, otherwise the charge will, during the removal of the envelopes, expand over *a*, and thus vitiate the result. The original experiment of Cavendish is far less precarious. The insulated globe was so much smaller than the hemispherical envelopes as to leave a space of about half an inch between them; a temporary conducting communication was established between the inner and outer spheres, by means of a short brass wire attached to an insulating silk thread, by which the wire could be easily removed. An electrical charge was communicated to the outer globe, in which case it is evident that if any part of the charge had a tendency to pervade the system as a mass, it could freely do so by means of the conducting wire; but on examination it was found that on removing the hemispheres by their insulating supports the inner globe did not exhibit any signs of Electricity, fully proving the tendency of Electricity to the surface. Again, the envelopes of the globe being removed, the latter may be charged with either positive or negative Electricity, and the covers being re-placed, a temporary communication may be established between the

inner and outer spheres, by means of a wire attached to a rod of unvarnished glass; on now removing the wire, and drawing back the hemispheres, the whole of the charge will be found upon them, and none whatever upon the originally charged interior globe.

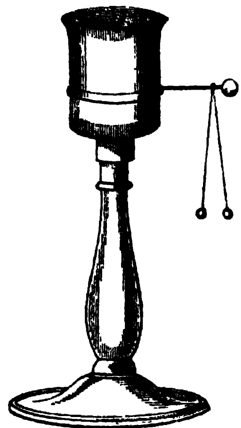
In Fig. 28 another of Biot's experiments is illustrated. A B is an insulated cylinder, moveable round a horizontal axis, which may be turned by a glass handle H. Around the cylinder there is wound a metallic riband C D, to the end of which is attached the silk cord F. This apparatus is made to communicate with a pith-ball Electroscope E; when the riband is electrified the balls of the Electroscope diverge; upon unrolling it by pulling the silk thread at F, the balls gradually collapse, indicating a diminution of electrical charge, and if the riband be sufficiently long, compared with the electrical charge given to the apparatus, they will entirely collapse, but will again diverge on re-rolling the riband on the cylinder.

Fig. 28.



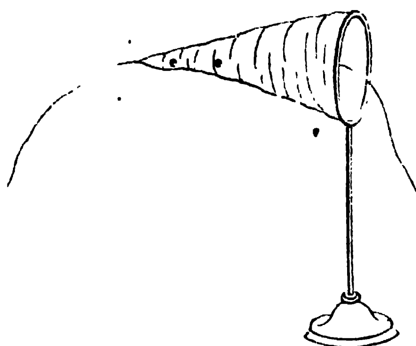
This experiment is a modification of one made long since by Franklin. The apparatus employed by that philosopher is shown in Fig. 29, and consisted simply of a metallic can and chain, insulated on a varnished glass pillar. A pair of pith-balls suspended by linen threads was hung on a wire projecting from the can. On electrifying the can by an excited glass rod, the balls diverge to a certain extent; on lifting up one end of the coiled chain by the silk thread *s*, and drawing it gradually out of the can, the divergency of the balls lessens, and finally becomes scarcely perceptible; on now again dropping the chain gradually into the can, the balls again begin to diverge, and the divergence increases till the whole of the chain has been returned, when it is nearly as great as at first.

Fig. 29.

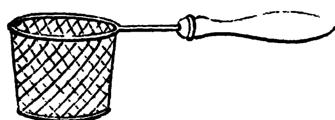


(85) The permanent residence of a charge on the external surface without regard to the nature of this surface is beautifully illustrated also by the following experiments of Faraday.

1°. A cylinder of wire gauze is placed on an insulating stand, and a small charge of Electricity communicated to its inner surface by means of a carrier ball; a Coulomb's proof plane is now applied to abstract a portion of this charge for testing; none can however be obtained, the whole being found on the outside of the gauze notwithstanding the free and open access between the sides.


Fig. 30.

2°. A conical muslin bag, stiff enough to preserve its form, is attached to a metallic hoop insulated on a varnished glass rod, and placed in a horizontal position, as shown in Fig. 30; a charge of Electricity is conveyed to the bag by means of a carrier ball, the Electricity arranges itself on the outside of the cone; the cone is now drawn inside out by means of a silk thread, so that the surface of the muslin which before formed the inner now forms the outer superficies; on applying the proof plane it is found that the charge has passed from one surface of the muslin to the other, in order still to be on the outside. This experiment may be varied thus:—A net of black thread is attached to a metallic hoop provided with an insulating handle, the lower end of the net is gathered round a circular metallic plate somewhat smaller than the hoop, so as to form a bag, an electrical charge is transferred by a carrier ball to the inside of the bag, the ball being made to touch the metallic plate, the charge is found arranged as before on the outside; by a dexterous movement of the hand the bag may be now turned inside out, upon which it will be found that the charge has followed the motion of the bag, and is still arranged on the outer surface. The experiments with the ice-pails (Fig. 26) are also beautiful illustrations of the determination of a charge to the surface of conductors, and the phenomena are in exact accordance with the corpuscular view of induction set forth by Faraday: "All charge of conductors is on their surface, because, being essentially inductive, it is there only that the medium capable of sustaining the necessary inductive state begins. If the conductors are hollow, and contain air or any other dielectric, still no *charge* can appear upon that internal surface, because the dielectric there cannot assume the polarised state throughout in consequence of the


Fig. 31.

opposing actions in different directions." (*Ex. Research*, series xi., p. 1301.)

(86) But the grandest experiment of this kind was that conducted by Faraday in the lecture room of the Royal Institution, his object being to ascertain whether air could be charged *bodily* with either kind of Electricity—whether Electricity could exist separate from matter. "I carried on these experiments with air to a very great extent. I had a chamber built, being a cube of twelve feet. A slight cubical wooden frame was constructed, and copper wire passed along and across it in various directions, so as to make the sides a large net-work, and then all was covered in with paper, placed in close connexion with the wires, and supplied in every direction with bands of tin-foil, that the whole might be brought into good metallic communication, and rendered a free conductor in every part. This chamber was insulated in the lecture room of the Royal Institution; a glass tube about six feet in length was passed through its side, leaving about four feet within and two feet on the outside, and through this a wire passed from a large electrical machine to the air within. By working the machine the air in this chamber could be brought into what is considered a highly electrified state (being, in fact, the same state as that of the air of a room in which a powerful machine is in operation), and at the same time the outside of the insulated cube was everywhere strongly charged. But putting the chamber in communication with a discharging train, and working the machine so as to bring the air within to its utmost degree of charge, if I quickly cut off the connexion with the machine, and at the same moment, or instantly after, insulated the cube, the air within had not the least power to communicate a further charge to it. If any portion of the air was electrified it was accompanied by a corresponding opposite action within the tube, the whole effect being merely a case of *induction*. Every attempt to charge air bodily and independently with the least portion of either Electricity failed.

"I put a delicate Electrometer within the cube, and then charged the whole by an outside communication, very strongly, for some time together; but neither during the charge, or after the discharge, did the Electrometer or air within show the least signs of Electricity. I charged and discharged the whole arrangement in various ways, but in no case could I obtain the least indication of an absolute charge, or of one by induction in which the Electricity of one kind had the smallest superiority in quantity over the other. I went into the cube and lived in it, and using lighted candles, Electrometers, and all other tests of electrical states, *I could not find the least influence upon them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface.* The

conclusion I have come to is, that non-conductors, as well as conductors, have never yet had an absolute and independent charge of one Electricity communicated to them, and that to all appearance such a state of matter is impossible." (*Ex. Research.*, series xi. 1173—4.)

(87) But though Electricity may be considered as confined to the surfaces of bodies, its intensity is not on every part the same. On a sphere, of course, the symmetry of the figure renders the uniform distribution of Electricity upon it inevitable; but if it be an oblong spheroid, the intensity becomes very great at the poles, but feeble at the equator. A still more rapid augmentation of Electricity at the extremities takes place in bodies of a cylindric or prismatic form, and the more so as their length bears a greater proportion to their breadth. Coulomb insulated a circular cylinder, two inches in diameter and thirty inches in length, of which the ends were hemispherical; and on comparing the quantities of Electricity collected at the centre and at points near the extremities, he obtained the following results:—at two inches from the extremity the Electricity was to that at the centre as $1\frac{1}{4}$ to 1; at one inch from the extremity it was as $1\frac{1}{2}$ to 1; and at the extremity it was as $2\frac{3}{10}$ to 1. From the observations of the same philosopher, it appears that the depth of the electric fluid on a conductor always increases in rapid proportion in approaching the edges, and that the effect is still more augmented at corners, which may be regarded as two edges combined; the effect is still further increased if any part of a conductor have the form of a point. In his researches Coulomb employed the proof plane and his balance of torsion; but as it has been rendered probable by the experiments of Harris that an indefinitely thin carrier plate cannot be altogether considered as an element of the surface of an electrified body to which it is applied, that it does not, in fact, fairly represent the actual amount of Electricity accumulated, it is possible that further investigation may render it necessary to modify, to some extent, the conclusions of the French mathematician.

(88) It was assumed also, by Coulomb, that the force which retains Electricity on the surface of a conductor is the pressure of the atmosphere, and the reason why it is impossible to accumulate any quantity of Electricity on a conductor furnished with points is because the depth of Electricity is there so much increased that the force of the electric fluid exceeds the restraining pressure of the atmosphere. But by adopting Faraday's theory of induction, founded upon a molecular action of the dielectric, we get rid of the necessity of associating two such dissimilar things as the "ponderous air and the subtile and even hypothetical fluid or fluids of Electricity, by gross mechanical relations." "An electrified cylinder is more affected by the influence of the surround-

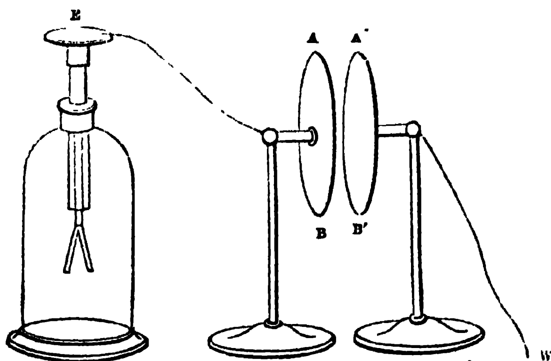
ing conductors (which complete the condition of charge), at the ends than at the middle, because the ends are exposed to a greater sum of inductive forces than the middle; and a point is brought to a higher condition than a ball, because, by relation to the conductors around, more inductive force terminates on its surface than on an equal surface of the ball with which it is compared," (*Ex. Research.*, xii., par. 1302.) The distribution of Electricity on the surface of an insulated sphere is only uniform as long as it is surrounded by a dielectric of the same specific inductive capacity, for when an electrified ball is partly surrounded by air and partly by sulphur or lac, the Electricity is diffused on it unequally, though the pressure of the atmosphere remains perfectly unchanged. Again, it has been shown by Harris (*Phil. Trans.*, 1834), that an electrified ball, insulated under the receiver of an air-pump, and connected with an Electroscope, undergoes no change by withdrawing $\frac{88}{90}$ths of the air, also that a charged Electroscope, enclosed in an air-tight bulb and placed under a receiver, retains its charge unaltered when $\frac{98}{100}$ths of the air is withdrawn, and that the divergence of a well-insulated gold leaf Electroscope does not diminish when the air of the receiver under which it is placed is exhausted till only $\frac{1}{300}$th part remains.

(89) *Condensers, multipliers.*—We are now prepared to understand the *rationale* of those instruments which have been contrived for the purpose of rendering evident very minute traces of Electricity. They have received various forms, but they all depend on the following considerations. If we communicate a charge of Electricity to an insulated metallic cylinder, provided at either end with a strip of gold leaf, as an Electroscope, the equal divergence of the two leaves will show the equality of the distribution of the Electricity at the two ends of the conductor. If we now bring near to one end of the electrified cylinder another similar cylinder, unelectrified and in free communication with the earth, we shall observe a remarkable disturbance to take place in the electrical condition of the cylinder: the gold leaf at the extremity nearest the second cylinder will become much more divergent, while the repellent effect of the other will be greatly diminished, and even reduced almost to nothing. On removing the uninsulated cylinder, the divergence of the two leaves will again become equal, and we may further observe that the nearer the neutral conductor is brought to the electrified one the greater the difference in the repellent power of the two leaves. Now, bearing in mind that "all charge is sustained by induction," we must consider the divergence of the gold leaves on the electrified conductor to be occasioned, not by any direct *repulsive* power exerted on them by the cylinder, but in consequence of induction through the air towards distant surrounding objects. When, therefore, a conducting body is brought very near to the insulated

electrified cylinder, induction is almost wholly directed through the air to it; if the second cylinder be insulated it will itself become electro-polar, but if it be in direct communication with the earth the Electricity of the same kind with that of the first cylinder will become virtually annihilated, by diffusion over the earth, and it will itself sustain nearly the whole of the charge on the electrified cylinder, hence the reason why the gold leaf nearest the second cylinder becomes more repellent than before and the other one less so. This *masking* or apparent neutralizing of a portion of the charge on the conductor, may be further shown by connecting the cylinder with the gold leaf Electroscope (49), the leaves of which will begin to collapse the moment the second cylinder is made to approach the first. The same fact may be still more simply shown without employing any metallic conductors at all, by merely bringing the hand over and close to the cap of the instrument, the charge on the cap and leaves, previously sustained by surrounding objects, will now be sustained nearly entirely by the hand alone, and the greater part of the charge being now concentrated on the cap, the leaves will collapse.

(90) It is important to bear in mind that none of the Electricity with which the Electroscope was charged is lost in this experiment; it is only diverted from the leaves to the cap, as is proved by the fact that, when the hand is removed the divergence of the former will, in a good experiment, return to its former extent. If now we substitute for the cylinders a pair of metallic discs, precisely the same results will be obtained.

Fig. 32.



Let E, Fig. 32, represent the cap and leaves of Singer's arrangement of Bennett's Electroscope, and A B the end view of an insulated metallic disc, connected with E by a metallic wire. On communicating a small charge of Electricity to A B it will be diffused over E, and the leaves will diverge to a certain extent; if we now approach A B with

a second and precisely similar disc, A′ B′, in free communication with the earth by the wire W, the leaves will gradually collapse, and when the two discs are almost in contact, the charge will be so far withdrawn from E and concentrated on A B that the gold leaves will hang nearly parallel; let A′ B′ be now suddenly withdrawn to a distance, the Electricity accumulated on A B being now relieved from the influence of A′ B′, will, in virtue of its expansive power, return and diffuse itself over E, the leaves of which will immediately return to their former state of divergence. Whilst the disc, A B, is under the influence of A′ B′, and the leaves of the Electroscope nearly converged, let a second quantity of Electricity be communicated to A B, sufficient to cause a sensible divergence of the gold leaves, then let A′ B′ be again suddenly withdrawn, the leaves will now open to a considerable extent, being influenced by the united forces of both the electrical charges thrown on A B. This is in fact the principle of the electrical condenser, originally invented by Œpinus, but brought into the service of electrical science by Volta. "It is," observes Dr. Lardner, "in the estimation of small quantities of Electricity, analogous to the microscope in the examination of visible objects, and it stands in the same relation to the Electroscope as the compound microscope holds to the micrometer, screw, and vernier in astronomical instruments."

(91) The laws regulating the inductive action of the discs on each other, and the operation of the direct and reflected inductive forces, have been investigated by Sir William Snow Harris, by some beautiful experiments made with his hydrostatic balance (63), (*Phil. Trans.*, 1834, and *Rudimentary Electricity*, 101, *et seq.*) The quantity of Electricity displaced from A′ B′ may be considered as the direct induction of the plate A B. In order to measure this induction, the wire connecting A′ B′ with the earth was removed, the plate itself being in communication with the plate *f* (Fig. 13) of the Electrometer, which then indicated, in degrees, the resulting force at the distance between the plates A B, A′ B′. These plates were then separated by other distances, and it was found that the forces, in degrees, as expressed by the Electrometer, were *inversely as the squares of the distances between the plates;* and as the quantity of Electricity is as the square roots of the forces, it appears that the *direct induced force is inversely as the distance.* The distances between the plates being constant and the quantity of Electricity being varied, it was found that the induced force was as the *exciting Electricity directly and as the distance inversely.* When A′ B′ was *insulated*, then the direct induction was no longer, as before, in a simple inverse ratio of the distances, but in *the inverse ratio of the square roots of the distances.* The amounts of reflected induction of A′ B′ on A B were next ascertained; they were found, when A′ B′ was uninsulated, to be in the *inverse ratio* of the

distances between the plates, while, when A′ B′ was insulated, the variation was as before, in the *inverse ratio of the square roots of the distances.*

(92) The original condenser of Volta was constructed as represented in Fig. 33. It consisted of two circular metallic discs, the surfaces of which were covered with a thin and uniform coating of amber varnish; the lower disc, B, was supported on a metallic stand, B D, the upper disc, A, called the *collector*, was provided with an insulating handle, and a short wire terminating in a metallic ball, E. The body, the Electricity of which was to be investigated, was brought into contact with E, the Electricity thus communicated to A, acting by induction through the thin non-conductor on B, confined the Electricity of the opposite kind, repelling its similar Electricity; at the same time B, being in perfect electrical communication with the earth, had a constant supply of neutral Electricity conveyed to it, which in its turn underwent a similar decomposition. This process lasted until the condenser had received the full charge answering to its surface. The collector, A, being suddenly raised by its glass handle, taking care to keep it parallel to the base, the Electricity accumulated upon it could be transferred to an Electroscope for examination. The plates may be placed vertically, and if made a foot or more in diameter are very efficient and powerful. It is usual, however, to attach them at once to the gold leaf Electrometer, in the manner shown in Fig. 34, where *a* represents the collecting plate and *b* the condenser, the brass stem of which is attached to a hinge, by means of which it can be rapidly approached to and withdrawn from *a*, in metallic connection with the Electroscope. Sometimes the collecting plate is screwed on the top of the Electroscope, the condensing plate resting upon it, and in communication with the earth, and occasionally the whole instrument is inclosed in a glass case, a vessel of quicklime being also inclosed to preserve the glass from hygrometric moisture.

Fig. 33.

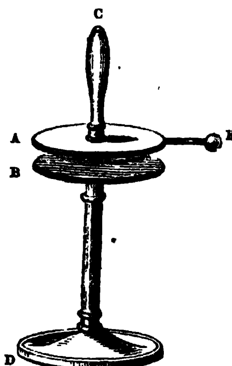
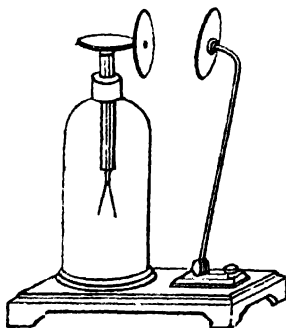


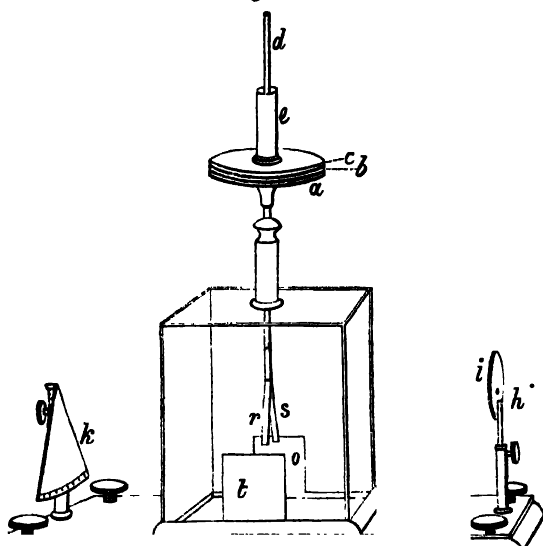
Fig. 34.



(93) An electrical condenser of remarkable delicacy was invented by M. Peclet, and is thus described by him (*Annales de Chimie et de Physique*, May, 1840).—The apparatus consists of three gilded plates superposed, a glass shade, containing the gold leaves, a three-footed

stand, furnished with adjusting screws, an eye-piece, and a portion of a divided circle. It is shown in Fig. 35. The inferior plate, *a*,

Fig. 35.



is metallically connected with the gold leaves, as in ordinary condensers, and is varnished on its upper surface alone. The plate *b*, which is placed above, is furnished with an insulating handle, *d*; it is varnished on both sides but not at its circumference; finally, the plate *c* is pierced at its centre by an orifice, through which passes the handle attached to the plate *b*; it is furnished with a cylinder of glass, *e*, serving to raise it, and is only varnished on its lower surface. These three plates are of ground glass, gilt, and then covered with many layers of gum-lac varnish. The lower plate, *a*, is in metallic connection with the two gold leaves, *r*, *s*, which are thin, narrow, parallel, and arranged as in ordinary condensers; these leaves are placed within a glass shade, large enough to allow the gold leaves to separate to their fullest extent without touching it. On the bottom of the case are fixed two plates of copper, *t*, *o*, destined to increase by their influence the divergence of the leaves, their height being so adjusted that the gold leaves may not, at any time, touch them. At the bottom of the shade is placed a box, containing chloride of calcium, to dry the air; the shade rests on a stand furnished with screws, by means of which the apparatus is rendered vertical. At one of the extremities of this stand, *h*, is a rod, supporting a circular plate, *i*, pierced at its centre with a very small hole; the other extremity is furnished with a section of a circle, *k*, divided into degrees; the heights of this

graduated piece and that of the centre of the plate *i* are so adjusted that the line which joins the two centres is horizontal, and also passes through the upper extremities of the gold leaves.

The instrument is used in the following manner:—the upper plate is touched with a metal held in the hand, and the edge of the second plate with the finger; the contacts are broken, the upper plate is removed and the lowest touched; the upper plate is then returned, and the same series of operations is several times repeated; finally, the two upper plates are removed by means of the rod *d;* the gold leaves diverge to a degree greater in proportion to the number of operations.

The *rationale* of the operation is this:—when the upper plate is touched by a metal held in the hand and the second with the finger, everything takes place as in the common condenser, the two plates become charged with the contrary Electricities, but disguised. When the first plate is removed these Electricities become free; but if the third plate is touched with the finger, the latter becomes charged and disguises the charge of the second; if then the first plate is restored to its place the second will be charged anew, and the charge may be made to pass in the same manner to the third. It is evident that if the Electricity of the upper plate did not dissipate itself it would suffice to touch it but once with the metal held in the hand; but to avoid the influence of that loss it is better to touch it at each operation.

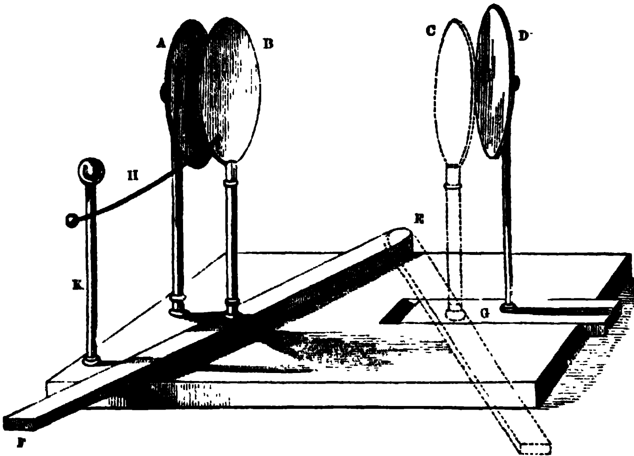
To give an idea of the condensing power of this instrument the following results are mentioned.—When the upper disc was touched with an iron wire twice, thrice, four, five, and six times, the divergence of the gold leaves amounted to $9\frac{2}{3}^{\circ}$, 20°, 25°, 31°, 41°, and 88°. When the experiment was made with a platinum wire, freed from all extraneous substances upon its surface by exposure to a red heat, and held in the hand after it had been washed with distilled water, a single contact indicated only a feeble divergence, but after three contacts it rose to 15°, and after twenty it amounted to 53°. This experimental demonstration of the existence of an electro-motory force between platinum and gold, and which had previously been wanting, was also obtained by M. Peclet with an ordinary condenser, the sensitiveness of which was carried to the utmost limits.

It appears, from M. Peclet's experiments with the double as well as the single condenser, that all metals are positive with regard to gold, and that in this respect their relative order is as follows,—zinc, lead, tin, bismuth, antimony, iron, silver, and platinum. Bismuth, antimony, and iron behave so like each other that their order in the series could be made out in no other way than by a very frequent repetition of the experiment.

(94) Of the various instruments that have been termed "multipliers"

and "doublers" we shall only describe the multiplier of Cavallo, it being very uncertain how far the indications of these instruments are to be relied on, as, from their extreme sensibility, they are liable to induce a low state of excitation during the manipulations performed with them, and thus to lead to equivocal results. Cavallo's multiplier is shown in Fig. 36. It consists of four metallic plates, A, B, C, D. The disc A is insulated on a glass pillar rising from the wooden base; B is also supported on a glass pillar fixed in a lever, E F, moving on a pivot, E; C is supported by a glass pillar standing on the base; and

Fig. 36.



D rises from a slider, G, and is uninsulated; by means of this slider C and B may be approached to and withdrawn from each other. At the back of B is fixed a metallic wire, H, which touches the metallic pillar, K, when the distance between A and B amounts to about the twentieth of an inch. The apparatus is used thus:—the body whose Electricity is to be examined is brought into contact with A, and B being, by the wire H, in communication, through K, with the earth, acts as a condenser, and becomes charged with the contrary Electricity. The lever, E F, is now moved to the position indicated by the dotted lines, and the contact between the wire, H, and the pillar, K, being broken, the Electricity of the condenser, B, is prevented from escaping to the earth, but is partly transferred to C, with which, by the motion of the lever, E F, it is brought into contact. But the uninsulated disc, D, acts as a condenser to C, and the consequence is, that nearly the whole of the charge on B is attracted to C: the lever is now restored to its former position and the process repeated, and may be continued until C becomes so charged with Electricity, that it can receive no more of the fluid from B; B is finally removed from A.

CHAPTER IV.

THE ELECTRICAL MACHINE.

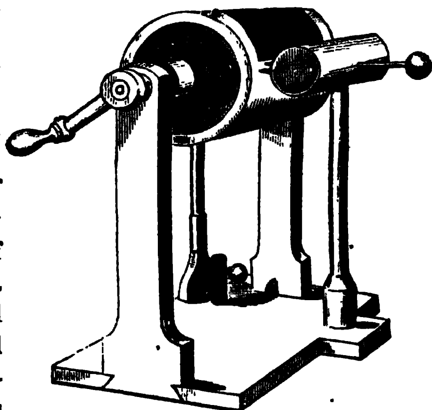
Various forms of the glass electrical machine—The steam-electric machine—Different forms of the disruptive discharge.

(95) *Electrical machines.*—The first apparatus that was constructed for the exhibition of electrical phenomena, to which the name of *electrical machine* was given, was the globe of sulphur used by Boyle and Otto Guericke (4), with which they discovered electric light. The substitution of glass for sulphur was made by Newton, the rubbers employed in both cases being the hand of the operator. That important part of the machine called the *prime conductor* was first introduced by Boze, (7), it consisted of an iron tube suspended by silken strings; and the substitution of a cushion for applying friction in the place of the hand, was first made by Winkler. Various were the forms now given to the electrical machine, for descriptions of many of which the curious reader is referred to Priestley's compendious *History of Electricity*, 1769. Dr. Watson's machine consisted of four globes turned by the same multiplying wheel, the Electricity being collected by one common conductor, and Dr. Priestley seems to have been the first electrician who employed a conductor supported by an insulating pillar. It was a hollow vessel of polished copper in the form of a pear. The insulating support was of baked wood, which was preferred to glass as being a better insulator and less brittle. The conductor received its " fire " by means of a long arched wire, or rod of very soft brass, easily bent into any shape, and raised higher or lower as the globe required, and it terminated in an open ring, in which were hung some sharp-pointed wires playing lightly on the globe when in motion. The rubber consisted of a hollow piece of copper filled with horse-hair, and covered with basil skin; on it was laid an amalgam made by rubbing together mercury and thin pieces of lead or tin-foil on the palm of the hand, and then mixing it into a paste with a little tallow. The electric was a glass globe with a single neck enclosed in a deep brass cap, mounted in a frame of baked wood and turned by a large multiplying wheel. The battery employed by Priestley consisted of sixty-four flint green glass jars, each ten inches long and two inches and a half in diameter; the coated part of each

was half a square foot; the whole battery contained thirty-two square feet.

(96) The electrical machines now constructed are exceedingly elegant pieces of philosophical apparatus, though they differ in form and arrangement almost as widely as the somewhat clumsy machines of the older electricians. There are two kinds of electrical machines in general use, the cylindrical and the plate machine. The former is shown in Fig. 37. It consists of a hollow cylinder of glass, supported on brass bearings, which revolve in upright pieces of wood attached to a rectangular base; a cushion of leather stuffed with horse-hair, and fixed to a pillar of glass, furnished with a screw to regulate the degree of pressure on the cylinder; a cylinder of metal or wood covered with tin-foil, mounted on a glass stand, and terminated on one side by a series of points to draw the Electricity from the glass, and on the other side by a brass ball. In order to keep the rubber and conductor warm and dry, Mr. Ronalds suggested in 1823 to support them on hollow glass tubes underneath which small lamps are placed. A more uniform temperature may however be obtained by placing underneath the cylinder a plate of metal about 6 inches square, and keeping it heated by an argand lamp. A flap of oiled silk is attached to the rubber to prevent the dissipation of the Electricity from the surface of the cylinder before it reaches the points. On turning the cylinder, the friction of the cushion occasions the evolution of Electricity, but the production is not sufficiently rapid or abundant without the aid of a more effective exciter, which experience has shown to be a metallic substance. The surface of the leather cushion is therefore smeared with certain amalgams of metals, which thus become the real rubbers. The amalgam employed by Canton consisted of two parts of mercury and one of tin, with the addition of a little chalk. Singer proposed a compound of two parts by weight of zinc, and one of tin; and Pfister a mixture of two parts tin, three zinc, and four mercury, with which in a fluid state six parts by weight of mercury are mixed, and the whole shaken in an iron, or thick wooden box, until it cools. It is then reduced to a fine powder in a mortar, sifted through muslin, and mixed

Fig. 37.



with lard in sufficient quantity to reduce it to the consistency of paste. This preparation should be spread cleanly over the surface of the cushion, up to the line formed by the junction of the silk flap with the cushion; but care should be taken that the amalgam should not be extended to the silk flap. It is necessary occasionally to wipe the cushion, flap, and cylinder, to cleanse them from the dust which the Electricity evolved upon the cylinder always attracts in a greater or less quantity. It is found that from this cause a very rapid accumulation of dirt takes place on the cylinder, which appears in black spots and lines upon its surface. As this obstructs the action of the machine it should be constantly removed, which may be done by applying to the cylinder, as it evolves, a rag wetted with spirits of wine. The production of Electricity is greatly promoted by applying to the cylinder with the hand a piece of soft leather, five or six inches square, covered with amalgam. This is in fact equivalent to giving a temporary enlargement to the cushion.

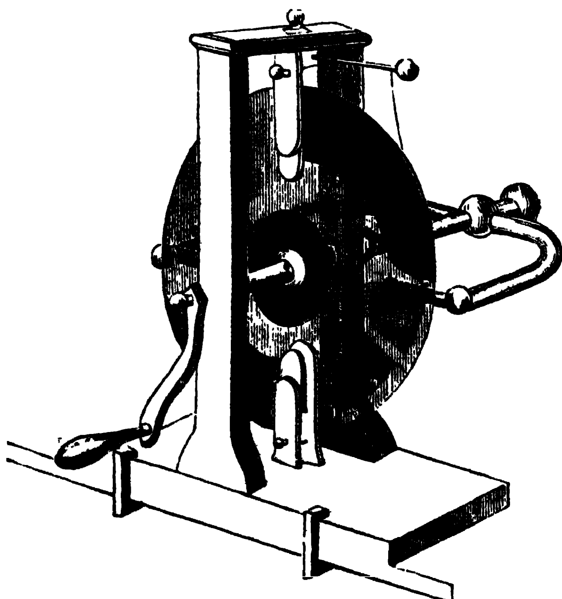
Peschel states (*Elements of Physics*, vol. iii. p. 32), that the most effectual method of using amalgam is to spread it pretty thickly on the cushion itself, and then to cover it with a piece of silk, so that the amalgam may not be in actual contact with the glass: a sufficient quantity will work through the silk when the glass presses against it. By this arrangement the inconvenience of smearing the glass is avoided. One important qualification of the rubber is, that the surface on which the amalgam is placed, should carry off as quickly and as completely as possible, the Electricity excited. To effect this, a piece of copper, or tin-foil, the same size as the cushion, is laid immediately under the surface coated with amalgam. If, however, the cushion is stuffed with metal filings instead of with horse-hair, this arrangement is not necessary. If the surface of the amalgam be covered with finely powdered *mosaic gold*, increased effects are said to be produced; but attention must be paid to the purity of this substance, or it may be inert or even injurious. According to Masson (*Archives de l'Electricité*, Sept. 1845), mosaic gold (bisulphuret of tin) sometimes contains as much as fifty per cent. of sal ammoniac, the hygrometric and conductric properties of which completely destroy its electric action. Before employing it, therefore, it should be reduced to a powder, and washed on a filter until it no longer gives any indications of the presence of sal ammoniac: it should then be carefully dried and employed in powder upon heated paper. Masson thinks that the bisulphuret of tin does not undergo decomposition, but that it becomes electrized by simple friction.

The use of the oiled silk flap is to prevent the dissipation of the Electricity evolved on the glass by contact with the air; it is thus

retained on the cylinder till it encounters the points of the prime conductor, by which it is rapidly drawn off. It is usual to cover with a varnish of gum lac those parts of the glass beyond the ends of the rubber, with a view of preventing the escape of the Electricity through the metallic caps at the extremities of the cylinder, and the inside of the flap is also sometimes coated with a resinous cement consisting of four parts of Venice turpentine, one part of resin, and one of bees' wax, boiled together for about two hours in an earthen pipkin over a slow fire.

(97) When the cylindrical machine is arranged for the development of either positive or negative Electricity, the conductor is placed with its length parallel to the cylinder, and the points project from its side, as in the machine shown in the figure. The *negative* conductor supports the rubber, and receives from it the negative Electricity not by induction, as is the case with the positive conductor, but by *communication*. If it be required to accumulate positive Electricity, a chain must be carried from the negative conductor (which of course is insulated) to the ground; if, on the other hand, negative Electricity be required, then the conductor must be put in communication with the earth, and the rubber insulated. We shall return to the consideration of this presently.

Fig. 38.

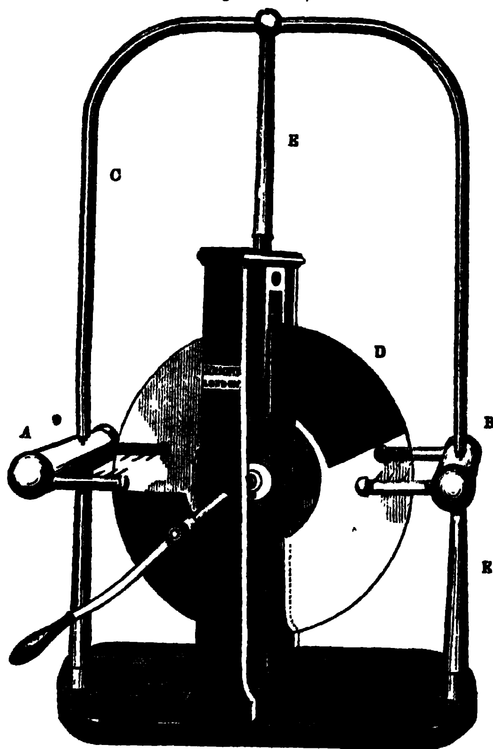


(98) The Plate Electrical Machine is shown in Fig. 38. It consists of

a circular plate of thick glass, revolving vertically by means of a winch between two uprights: two pairs of rubbers, formed of slips of elastic wood covered with leather, and furnished with silk flaps, are placed at two equi-distant portions of the plate on which their pressure may be increased or diminished by means of brass screws. The prime conductor consists of hollow brass, supported horizontally from one of the uprights; its arms, where they approach the plate, being furnished with points.

(99) With respect to the merits of these two forms of the electrical machine, it is difficult to decide to which to give the preference. For an equal surface of glass the Plate appears to be the most powerful; it is not, however, so easily arranged for negative Electricity, in consequence of the uninsulated state of the rubbers, though several ingenious methods of obviating this inconvenience have been lately devised.

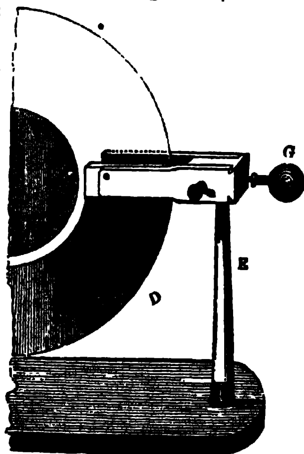
Fig. 39. (1)



(100) One of the best forms of the Plate Machine is that invented by Mr. C. Woodward, President of the Islington Literary and Scientific Institution. Fig. 39 represents the one in that Institution, presented to

the members by the above-mentioned gentleman. The plate, which is two feet in diameter, is fixed in the ordinary manner, between two uprights, to the top and bottom of which are attached the rubbers. The two conductors, A B, insulated on stout glass pillars, are fixed at each end of the mahogany board on which the whole is mounted, and connected together by a brass arm C, which is supported in the centre by a glass pillar E; *from these points project and collect the* Electricity *from* both sides of the plate. This machine possesses the following advantages: the insulation is exceedingly good; it occupies but very little room on the lecture table; and readily exhibits positive and negative Electricity: for this latter purpose, it is arranged as follows, and the annexed cut will render it perfectly intelligible. The right-hand conductor B, together with the brass arm and support, are removed, and the plate being turned a quarter of a circle, the upper rubber D is brought down on the glass pillar E, and a brass ball G screwed into it. We have now a positive and negative conductor; and although the machine possesses, of course, but half its original power, it is sufficient for all purposes of experiment. Instead of one, this machine is readily mounted with two plates, which work equally well, and it then becomes an exceedingly powerful instrument, occupying scarcely any more space.

Fig. 40. (2)



Mr. Woodward strongly recommends the covering the glass pillars, and also that part of the plate between the spindle and the rubbers, with sealing-wax varnish, stating that it very much increases the power of the machine.

(101) In Sturgeon's *Annals of Electricity*, &c. for September, 1841, two useful modifications of the cylinder and plate machine are described and lithographed. The principal feature in which the arrangement of Mr. Goodman's cylinders differs from those of the usual construction, consists in their being supplied with *two* rubbers, mounted on glass rods placed parallel to each other on opposite sides of the cylinder, and connected together by means of a brass tube bent twice at right angles. This brass tube rises several inches above the top of the cylinder, so as to be out of the way of the prime conductor, which is so contrived as to answer at the same time for a support for one of the pivots on which the cylinder revolves. Two arms proceed from the upper and lower portion of this upright conductor, passing parallel to, and above

and below the cylinder, from which a number of points project to receive the fluid accumulated by the excitation of the rubbers, and brought round by the rotation of the cylinder. To prevent dissipation of the fluid from the extremities of the arms, each is made to terminate in a *lacquered glass ball.* Machines arranged in this manner are stated by the inventor to possess the desirable qualities of strength and endurance, and for equal surfaces to be twice as powerful as when only one rubber is employed.

Mr. Goodman arranges the rubbers of his plate machine in a similar manner, that is, parallel to each other, and supported by glass pillars on either side of the periphery of the plate, as in the cylinder machine, one end of the axis (of lacquered glass) turns in an insulated conductor provided with horizontal arms carrying points.

For common purposes, and where extreme cheapness is desirable, the plate may be made of common window-glass, to the centre of which two wood-turned convex caps may be cemented without any perforation of the plate, and the axle is completed by cementing a glass rod to the centre of each cap. The cement recommended by Mr. Goodman, is equal parts of resin and bees' wax, made sufficiently thick by the addition of red-ochre. The cost of a plate of fifteen inches in diameter is about two shillings, or half a crown.

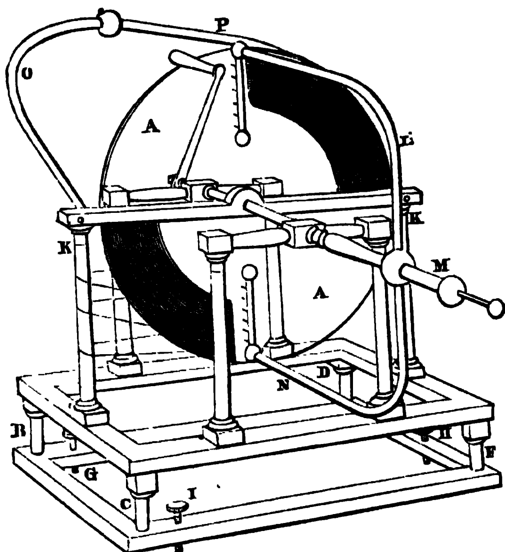
(102). Van Marum in conjunction with Mr. Cuthbertson constructed an electrical machine of extraordinary power, towards the end of the last century. It consisted of two circular plates of French glass, each sixty-five inches in diameter, fixed upon the same axis and excited by four pairs of cushions each nearly sixteen inches in length. A single spark from this machine melted a leaf of gold; a thread became attracted at the distance of thirty-eight feet, and a pointed wire exhibited the appearance of a luminous star at a distance of twenty-eight feet from the conductor

A magnificent machine, somewhat on Van Marum's principle, has lately been constructed for the Royal Panopticon of Science and Art in Leicester Square. The plate of this machine is ten feet in diameter, it is turned by steam power, and excited by three pairs of rubbers, each pair nearly three feet in length. The conductor, which is pear-shaped on Priestley's plan, is six feet long and four feet in diameter in its widest part. When well excited, sparks from fifteen to eighteen inches in length, and of remarkable brilliancy and volume, may be drawn from the terminal ball of the conductor; the discharge through a vacuous tube seven feet long, exhibits a continuous stream of splendid purple light, and it charges to saturation a battery of thirty-six jars, presenting 108 square feet of coated glass, in less than a minute.

(103) Sir William Harris's elegant machine is shown in Fig. 41.

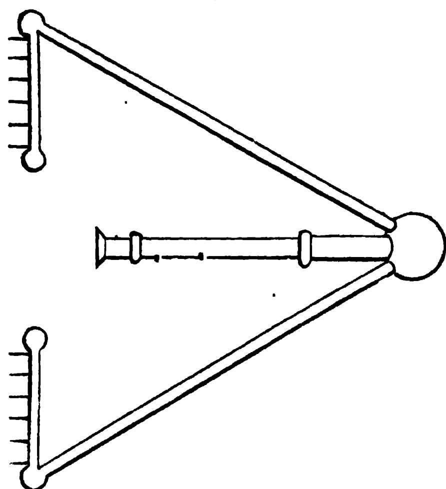
The plate A A, about three feet in diameter, is mounted on a metallic axis resting on two horizontal supporters of mahogany, which are themselves sustained by four vertical mahogany columns, fixed

Fig 41.



upon a firm frame as a base. The whole apparatus rests on the four legs, B C D F, and these again rest upon another steady frame provided with three levelling screws, G H I, for securing it in a horizontal position. The rubbers are insulated on the glass pillars, K K, one on either side of the horizontal diameter of the plate. L M N is the positive conductor projecting in a vertical position in front of the plate, while the negative conductor, O P, passes in a curvilinear direction behind, and connects the rubbers of each side.

The glass plate is turned by an insulated handle, immediately in front of which is placed a short index, which is fixed to the axis, and which moves over a graduated circle attached to the horizontal part of the frame, and through the centre of which the axis passes. In this manner the number of revolutions of the plate may be accurately registered. In order to strengthen the centre of the plate, two smaller plates are cemented to each side by varnish, and a small stop is inserted into the axis to prevent the pressure from increasing beyond a certain point.


Fig. 42.

When the machine is used for ordinary purposes, the conductors, as shown in Fig. 42, are employed, but when it is required to accumulate Electricity, the conductors should have the smallest extent possible. They are thus formed of small straight tubes, as shown in Fig. 42, and its extremities terminate in balls of varnished wood, through the substance of which the metallic communicators pass. To prevent the flaps from being dragged over the plate in turning, they are retained in their places by cords of silk attached to them, passing round fixed supports.

The machine used by Faraday, in his famous researches, is somewhat in construction similar to Harris's; the plate is fifty inches in diameter, the metallic surface of the conductor in contact with the air is about 1422 square inches; when in good excitation one revolution of the plate will give ten or twelve sparks from the conductor, each an inch in length. Sparks or flashes from ten to fourteen inches in length may easily be drawn from the conductors.

(104) It is by no means immaterial what *kind of glass* is employed in the construction of the plates or cylinders of electrical machines. Priestley, who made many experiments on this subject, came to the conclusion "that common bottle metal is fittest for the purpose of excitation," in consequence (as he rightly supposed) of the hardness of the metal and its exquisite polish. Harris recommends the flinty kind of plate-glass of most perfect manufacture, and very highly polished. Common window-glass is admirably adapted to the purposes of electrical excitation. Sir William constructed a machine of two feet in diameter, by cementing together two plates of window glass with black sealing-wax, and he states that it had most remarkable power. The softer kinds of glass and those in which the alkalies predominate are very inferior, and some kinds cannot be excited at all in consequence of their remarkable conducting power.

(105) The eminent electrical properties of gutta percha (35) would suggest the employment of this substance as a negative electric for electrical machines. Mr. Barlow (*Phil. Mag.* vol. xxxvii. p. 428) describes an

apparatus of this kind, consisting of a band of thin sheet gutta-percha about four inches wide, which is made to pass round two wooden rollers fitting them very tightly, and rubbed by four brushes of bristles placed outside the band and opposite to the axis of each roller. The machine is provided with a curved brass conductor similar in form to the conductors of plate-glass machines: under favourable circumstances this machine acts very well; but Mr. Barlow finds it much affected by the weather, and he thinks that although gutta-percha is capable of producing a large amount of Electricity, a modification must be effected in the construction of the machine before it can take its place as a useful instrument.

(106) At the concluding stage of the manufacture of paper, viz., when it leaves the glazing or polishing iron rollers, and accumulates in a finished state on a final wooden roller, powerful electrical phenomena are frequently developed; the Electricity is *negative*. Messrs. Armstrong (*Elect. Mag.* vol. i., p. 459), Hankel (*Poggendorf's Annalen*, vol. xxxi., p. 477), and Walker (*Elect. Mag.* vol. ii., p. 120), have studied the conditions under which this electrical excitement takes place. The electrized condition of the paper becomes perceptible immediately after the sheet quits the last glazing roller; and when a person's hand is presented, either to the roll of finished paper, or to any part of the sheet between the roll and the glazing rollers, sparks are emitted by the paper which sometimes reach to a distance of several inches, and when the interior of the room is darkened, the workmen frequently see sparks darting through a space of eight or ten inches between the surface of the roll and the iron work of the machine. By means of a collector, consisting of a row of metallic points insulated by a glass handle, Mr. Armstrong charged Leyden jars, but the quantity of Electricity evolved was not so great as appearances led him to expect. Dr. Hankel found that the heat of the last steam roller exercised great influence, the electrical phenomena being much stronger the more the heat of the last steam roller was increased, becoming in fact frequently so strong that very loud sparks darted from the paper to the last smoothing roller, by which jars could readily be charged. In Mr. Elliot's mill, near Chesham, Bucks, sparks from ten to twelve inches long have been obtained from the wooden roller round which the paper is collected; the greatest effects were produced by a thin brown paper manufactured for Terry's "poor man's plaster." Walker found this paper to be quite free from Electricity previous to its undergoing the final act of pressure between the polishing rollers. The cause of electrical excitement is the pressure and withdrawal of pressure (amounting in fact to friction), which the paper undergoes in its passage through the roller.

(107) A similar production of Electricity has for many years been noticed in Mr. Macintosh's manufactory at Glasgow, on tearing asunder

the well known waterproof-cloth which is stuck together by means of a solution of India-rubber in coal tar (*Edin. Phil. Jour.* vol. x., p. 185). It has also been noticed by Mr. Marsh, during the grinding of newly roasted coffee in an iron coffee mill (*Ann. of Elect.* vol. viii., p. 124). Powerful electrical phenomena have likewise been observed in cotton mills, arising from the friction of the bands or straps over the rollers by which the machinery is put in motion; and lastly, strong electrical sparks have been obtained, where neither friction nor pressure has intervened to produce electrical excitement, as for instance during the drying of dyed or bleached goods, which, according to Mr. Napier (*Elect. Mag.* vol. i., p. 500), become sometimes so highly excited that sparks, visible in daylight, will be given off to an individual passing close to them. Pieces mordanted with acetate of alumina and dried at a great heat, are often highly charged with Electricity, and if the hand be suddenly drawn along the piece, a complete shower of fire is observed with a sharp crackling noise accompanied by a slight shock. Mr. Buchanan relates (*Phil. Mag.* N. S. vol. i., p. 581), that in a factory at Glasgow, the accumulation of Electricity in one room in particular, in which was a large cast-iron lathe, shears, and other machinery driven with great velocity by leather belts, was so great that it was necessary, in order to protect the workmen from unpleasant shocks, to connect the machinery by means of a copper wire with the iron columns of the building; and that when a break in the wire of $\frac{1}{12}$ of an inch was made, the intermediate space was constantly luminous, and even at $\frac{1}{4}$ of an inch the succession of sparks was very rapid. The Electricity was positive.

(108) Scientific men are not agreed as to the *modus agendi* of the amalgam applied to the rubber of the electrical machine. It seems pretty clear that the oxidation of the amalgam by the friction employed is essential to the increased excitation; for the development of Electricity does not appear to be increased when amalgams of difficultly oxidizable metals, such as gold, are employed; and Dr. Wollaston could not succeed in obtaining any signs of free Electricity from a machine worked in an atmosphere of pure carbonic acid. The bisulphuret of tin (aurum musivum) may be employed instead of amalgam; by the friction it probably becomes partially decomposed into bisulphate of tin, as iron pyrites is into sulphate of iron. The chemical influence of friction, indeed, is more energetic than is usually supposed: even siliceous minerals, as mesotype, basalt, and feldspar, become partly decomposed, giving up a portion of their alkali in a free state.

(109) The theory of the action of the electrical machine flows immediately from the principles of induction already illustrated (79); a brief recapitulation may, however, be useful. On turning the handle of the cylinder, or plate, the Electricity naturally present in the rubber

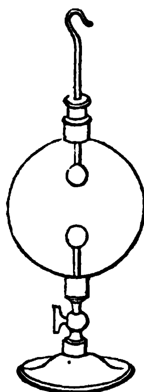
becomes decomposed,—its positive adhering to the surface of the glass, and its negative to the rubber: the positive electric portions of the glass coming, during its revolution, opposite to the points on the conductor, act powerfully by induction on the natural Electricities of the conductor, attracting the negative, which being accumulated in a state of tension at the points, darts off towards the cylinder, to meet the positive fluid, and thus re-constitute the neutral compound. The consequence of this is, that the conductor is left powerfully positive,—*not*, it must particularly be understood, *by acquiring Electricity from the revolving glass, but by having given up its own negative fluid to the latter*. The rubber is left in a proportionately negative state, and consequently, after revolving the glass for a few minutes, can develop no more free positive Electricity, provided it is insulated: on this account, it is necessary to make it communicate with the earth for the purpose of obtaining a sufficient supply of positive Electricity to neutralize its negative state. In very dry weather, it is necessary to connect the rubber with the moist earth by means of a good conductor; and it is advisable, if possible, to establish a metallic connexion with metallic water pipes.

(110) The subjoined experiments will serve to familiarize the student with the principles and action of the electrical machine.

Ex. 1. See that the machine is in good working order, the cylinder or plate being free from dirt and black spots (96), and perfectly dry and warm: wipe it well with a piece of warm flannel, and then with an old silk handkerchief. Take care that the insulating glass stands are clean and dry, and see that the rubber is uniformly but not too thickly covered with amalgam (96). All these particulars being duly attended to, turn the handle, and present the knuckle of the other hand to the prime conductor; a vivid spark will pass between them accompanied by a sharp, snapping sound. It is usual to speak of this spark as the *positive spark*, a term which does not, however, convey a correct idea of its nature; for it is not to be regarded as arising from the mere passage of free Electricity, but as the union of the two electric fluids, and the consequent discharge of the electrified body. According to the principles of induction (70 *et seq.*) the positively electrified prime conductor induces an opposite state in any conducting substance approaching it, and when this state has amounted to one of sufficient *tension*, the negative Electricity rushes towards the positive of the prime conductor, constituting the neutral combination. It is this neutralization, or discharge of the electric state of the conductor, which constitutes the electric spark; and it is the same with the sparks from an excited glass tube, and from the cover of an Electrophorus (76): all cases of discharge must be preceded by induction (82). In order to obtain

long sparks from the prime conductor the operator must commence by taking short ones, and gradually lengthen them to their maximum. Long sparks in the open air are always crooked; this arises from the condensation of the air immediately before the spark in consequence of the immense velocity with which it moves; a resistance is thereby set up in the line in which it was moving, so that it changes its course, again condenses the air, and is again turned aside; and this alternate deflection produces a zig-zag appearance. Short sparks are either quite straight or slightly curved, sometimes broken and irregular. In condensed air the light is white and brilliant; in rarefied air divided and faint, and in highly rarefied air purplish. For these experiments the simple apparatus shown in Fig. 43 may be employed, consisting of a glass globe about four inches in diameter, provided at each end with a brass cap to one of which a stop-cock is screwed with a wire and ball projecting into the globe, and through the other a similar wire slides through a collar of leather, so that the balls may be set at any required distance from each other in the globe. The apparatus may be exhausted of air by the air-pump; or the air may be condensed in it by a condensing syringe. The effect of different gases may likewise be studied with this apparatus.

Fig. 43.



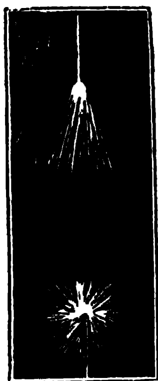
Ex. 2. Continue to turn the cylinder or plate, keeping the knuckle steadily held towards the prime conductor. The sparks will decrease in brilliancy, intensity, and frequency, and after some time no more will be obtained. Now establish a good metallic communication between the rubber and the earth, and the sparks will be obtained uninterruptedly, and undiminished in intensity.

Ex. 3. Remove the conductor from its position in front of the glass, and having darkened the room, revolve the cylinder or plate; a series of bright sparks will be observed to pass round the surface of the glass, exhibiting a very beautiful appearance. Let an assistant next take a needle in his hand, and approach its point towards, but at a considerable distance from, the revolving glass. While at the distance of several feet, it will be seen to be tipped with luminous matter, illustrating in a simple manner the striking influence of points, and their use on the prime conductor.

Ex. 4. Remove the ball from the end of the conductor disclosing a rounded blunt wire; put the conductor in its place, and turning the machine briskly, attempt to draw sparks from the body of the conductor with the knuckle, you will find that you will obtain very feeble and powerless ones, but you will perceive a beautiful luminous

appearance proceeding from the end of the wire, and on holding the hand near it, a sensation like that produced by a gentle stream of wind will be experienced. Notice attentively the appearance of the luminous matter at the points at the two opposite ends of the conductor: that on the points immediately opposed to the revolving glass will resemble small stars, and that on the wire at the end of the conductor will resemble a brush or pencil. The appearance of each will be found to be not unlike Fig. 44. The same luminous appearances will be perceived if a pointed wire be held at a short distance from the conductor and rubber, both being insulated, the *brush* or *pencil* appearing on the wire held towards the rubber, and the star on the wire presented towards the conductor. We shall return to the consideration of this electric light presently.

Fig. 44.



Ex. 5. Connect the rubber and conductor together by a wire: on revolving the glass, no signs of Electricity will be obtained from either: but if the machine be extremely energetic, the wire will appear surrounded with a lambent flame, otherwise the electric fluids will traverse, and the discharge take place invisibly along the wire. But if the conductor be interrupted, vivid sparks will appear at each rupture of continuity, arising from inductive action, and consequently discharge taking place at every one of these spots.

Ex. 6. The last experiment proves that the charges on the conductor and rubber are exactly equal: that they are in opposite electrical states may be proved by suspending from each some light substances, as feathers or pith-balls, which will strongly attract each other when the machine is put in action.

Ex. 7. Place several strips of paper upon the end of a long rod in connexion with the prime conductor, in the centre of a large apartment, they will open out equally, like radii from the centre of a sphere; but on approximating a conducting body to them in their charged state, they will incline towards it from the concentration of the force upon its nearer surface.

Fig. 45.



This is illustrated by the ridiculous figure of a *head of hair*, Fig. 45, and is a common electrical experiment. When electrified, the hair stands on end; and each fibre, as if in a state of repulsion from its neighbour, is attracted by, and radiates towards, the point which is nearest to it in the oppositely induced state.

Ex. 8. Paste some strips of tin-foil on a plate of glass having

portions cut out, so that the space represents letters, as shown in

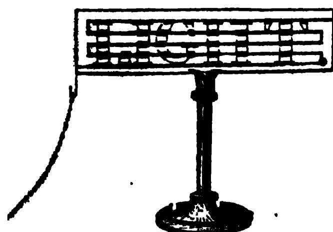
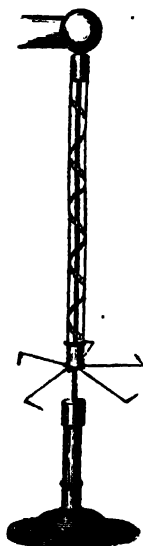

Fig. 46.

Fig. 46; or draw a serpentine line on the glass with varnish, and place on it metallic spangles about one-tenth of an inch apart; or stick the spangles in a spiral direction on a glass tube: in each case lines of fire, occasioned by sparks passing apparently at the same moment through all the spaces, will be observed on connecting the first piece of foil with the conductor, and the last with the ground. Fig. 47 represents a little apparatus invented by Mr. Barker for exhibiting the revolution of a spotted tube. It is made of a glass tube, blown smooth and round at one end, and open at the other: it should be about ten inches long, and three quarters of an inch in diameter. A ball or a piece of smooth tin-foil is fixed at the upper closed end, and the usual spots of tin-foil carried in a spiral form to the lower open end. A cap, either of wood or brass, is cemented on the outside of the lower end of the tube, and a strip of foil placed round it. From this ring four wires project outwards, having their points bent at right angles. The tube is then set on an upright wire which passes upwards into the tube to its top, and this wire is then set on an insulated stand, and brought near the prime conductor. It can thus revolve with great ease.


Fig. 47.

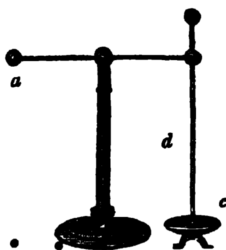
Ex. 9. Provide a stool with glass legs, Fig. 48, and having wiped it clean and dry, let a person stand upon it, holding in his hand a chain or wire communicating with the prime conductor: on setting the machine in action, sparks of fire may be drawn from any part of his person; he becomes, indeed, for the time, a part of the conductor, and is strongly electrified, although without feeling any alteration in himself. If he hold in his hand a silver spoon containing some warm spirits of wine, another person may set it on fire by touching it quickly with his finger.


Fig. 48.

Ex. 10. By employing the little arrangement shown in Fig. 49, cold spirits of wine may be fired. Place it so that the ball *a* can receive sparks from the prime conductor: pour spirits of wine into the cup *e*,

till the bottom is just covered: place the cup under the wire *d*, then turn the machine, and the sparks that are received by *a* will fly from the wire through the spirits to the cup, and generally set it on fire.

Fig. 49.



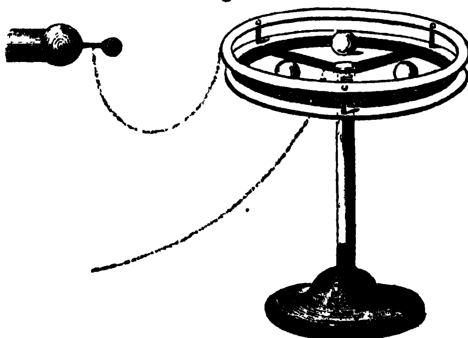
Ex. 11. The phenomena of attraction and repulsion are well illustrated by the apparatus known as the electric bells, Fig. 50. They are to be suspended from the prime conductor by means of the hook: the two outer bells are suspended by brass chains, while the central, with the two clappers, hang from silken strings: the middle bell is connected with the earth by a wire or chain: on turning the cylinder, the two outside bells become positively electrified, and by induction the central one becomes negative, a luminous discharge taking place between them, if the Electricity be in too high a state of tension. But if the cylinder be slowly revolved, the little brass clappers will become alternately attracted and repelled by the outermost and inner bells, producing a constant ringing as long as the machine is worked.

Fig. 50.



Fig. 51 shows an admirable contrivance for illustrating electrical attraction and repulsion. Three or four glass balls, made as light as

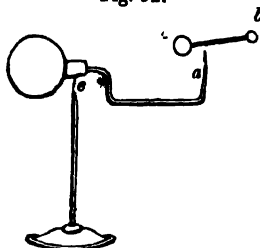
Fig. 51.



possible, are supported on an insulated glass plate, on the under part of which strips of tin-foil are so pasted as to form a broad circle or border near the margin, and four radii to that circle; on the upper part of the plate is a flat brass ring supported on small glass pillars, so as to have its inner edge immediately over the exterior edge of the tin-foil. The brass ring being in communication with the prime conductor and the

tin-foil with the rubbers of the machine, the ring and foil will be oppositely electrified. The glass balls being attracted by the ring, become positively electrified in the part which comes in contact with it. Thus electrified, they will be attracted by the foil, and communicating the charge, return to the ring to undergo another change. Different parts undergo in succession these changes, and the various evolutions of the balls are very striking and curious.

Fig. 52.



Ex. 12. The current of air which accompanies the discharge of Electricity from points is pleasingly shown by a variety of toys. Fig. 52 exhibits a little arrangement usually called the electrical planetarium. It is connected with the prime conductor by means of a chain, and when the machine is set in action the currents of air discharged from points inserted at *a* and *b* re-act on the wires of the apparatus, and it begins to move, gradually acquiring a very rapid horizontal motion, *c b* round the point *a*, and *a d* round the point *e*.

Fig. 53.

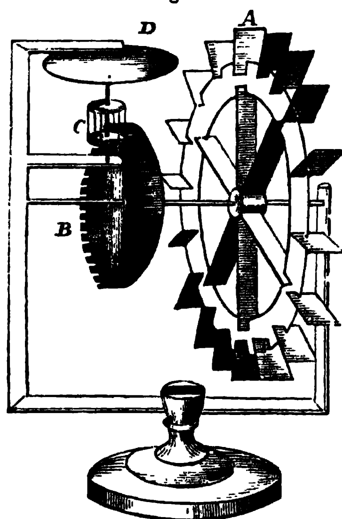


Fig. 53 represents a model of a water-mill for grinding corn. A is the wheel, B the cog-wheel on its axis, C the trundle, D the running millstone on the top of the axis of the trundle. To set it in motion place it near the prime conductor, in which is inserted a crooked wire terminating in a sharp point. Let this point be directed to the uppermost side of the wheel A. On putting the machine in motion, the current of air attending the Electricity which issues from the point will turn the wheel, and, consequently, all the other working parts of the mill.

Ex. 13. Fill a phial with oil, pass through the cork a copper wire bent ear its lower end at right angles, so that its point may press against the inside of the glass, and suspend it by the upper end of the wire from the prime conductor. From the machine the point of the wire in the phial will assume a high state of positive electric tension: bring towards it a brass knob, or the knuckle; induction, and consequent discharge, will take place through the sides of the glass, which will become perforated by a round hole.

Ex. 14. By the following beautiful experiment, the resistance to induction and discharge offered by a dielectric medium, such as atmospheric air, is shown. A glass tube A, Fig. 54, two feet in length, is furnished at either end with a brass ball projecting into its interior, and carefully exhausted of its air by means of a good air-pump: on connecting the end B with the prime conductor, and the end B' with the

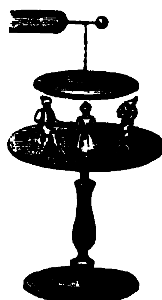
Fig. 54.



earth, when the machine is turned, B becomes positive, and induces a contrary state on the ball B', induction taking place with facility in consequence of the atmospheric air being removed (or rather highly rarefied), and is followed by a discharge of the two Electricities in the form of a beautiful blue light, filling the whole tube, and closely resembling the aurora borealis.

Ex. 15. Attraction and repulsion are amusingly shown by suspending a brass plate, Fig. 55, from the prime conductor, and setting under it a sliding stand, on which is laid a little bran or sand, or little figures made of pith: on turning the machine the bran or sand is attracted and repelled by the upper plate with such rapidity that the motion is almost imperceptible, and appears like a white cloud between the plates, and the little figures appear to be animated, dance, and exhibit very singular motions, dependent on inductive action.

Fig. 55.



Ex. 16. Fig. 56 represents a small pail with a spout near the bottom, in which is a hole just large enough to let the water out by drops; it is to be filled with water and made fast to the prime conductor: on turning the machine, the water which before descended from the spout in small drops only, will fly from it in a stream, which in the dark appears like a stream of fire; or a sponge saturated with water may be suspended from the prime conductor, when the same phenomenon will be observed, which is referable to the mutual repulsive property of similarly electrified particles.

Fig. 56.



Ex. 17. Let the tumbler A, Fig. 57, be wiped thoroughly dry, warmed, and the inside charged by holding it in such a direction that a wire proceeding from the prime conductor of a machine in action shall touch it successively in nearly every part; then invert it over a number of pith-balls; they will be attracted and repelled backwards and forwards, and effect the discharge of the Electricity which induces from the interior

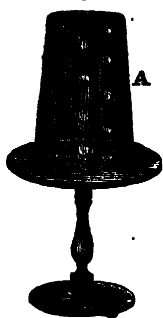


Fig. 57.

towards the plate. They will then remain at rest; but if the Electricity which has been disengaged on the outside towards surrounding objects be removed by a touch of the hand, a fresh portion will be set free on the interior, and the attraction and repulsion of the balls will again take place, and thus for many times successively the action will be renewed until the glass eturns to its natural state.

Ex. 18. Fig. 58 is another amusing philosophical toy. It is called the electrical swing, and acts, as will be immediately perceived, upon the principle of attraction and repulsion. The insulated brass ball A is connected with the prime conductor, while the opposite ball B communicates with the earth. The light figure represented as sitting on a silken cord is first drawn towards A, where it receives a charge which it discharges on B, and thus is kept swinging between the two balls.

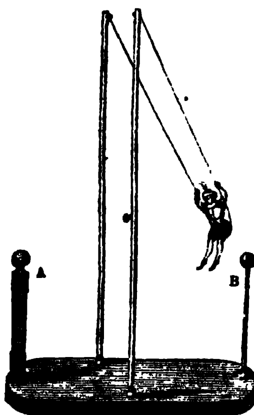
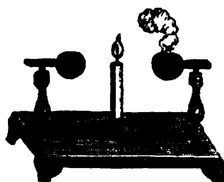


Fig. 58.

Ex. 19. Fig. 59 represents two hollow brass balls, about three quarters of an inch in diameter, insulated on separate glass pillars, by which they are supported at a distance of about two inches from each other; the upper part of each ball is hollowed into a cup, into which a small piece of phosphorus is to be put. A small candle has its flame situated midway between the balls, one of which is connected with the positive, and the other with the negative conductor of a powerful machine. When the balls are electrified, the flame is agitated, and, inclining towards the one which is *negative*, soon heats it sufficiently to set fire to the phosphorus it contains, whilst the positive ball remains perfectly cold, and its phosphorus unmelted. On reversing the connexions of the balls with the machine, the phosphorus in the other ball will now be heated, and will inflame.

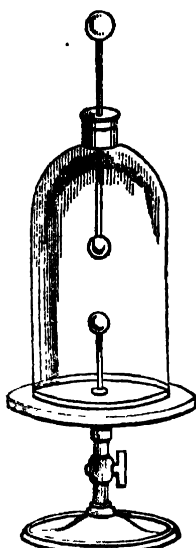

Fig. 59.

Ex. 20. To a wire proceeding from the prime conductor, attach a piece of sealing-wax; put the machine in action, no effect will be produced on the wax: now soften the end by the flame of a spirit lamp, and while the machine is in action, present a card to the hot wax, and it will be perceived that a considerable quantity of melted wax has been blown off from the wire, and, in the form of fine, soft, flexible

filaments, has collected on the surface of the card, exhibiting a very curious appearance. This experiment is interesting, as proving that the mechanical condition of bodies has an influence on their relation to Electricity. The sealing-wax, when cold, stands high amongst non-conductors; but when the physical condition of its atoms is disturbed by heat, it becomes a conductor.

Ex. 21. With the apparatus shown in Fig. 60 some exquisitely beautiful electrical experiments may be made. The balls in the receiver, which may be 12 or 14 inches high and 6 or 7 inches in diameter, are set opposite to each other at the distance of about four or six inches. The receiver is accurately exhausted, and then screwed on the transfer plate, which is connected by a wire with the negative conductor, the upper ball being connected with the positive. On turning the machine a current of beautiful light will pass from the positive to the negative ball on which it breaks and divides into a luminous atmosphere entirely surrounding the lower ball and stem, and conveying in a very striking manner the idea of a fluid running over the surface of a resisting solid which it cannot enter with facility. No appearance of light occurs on the positive ball but the straight luminous line that passes from it; but if it be rendered negative, and the lower ball positive, these effects are reversed. If the lower ball and wire be altogether removed, and if the upper wire be made to terminate in a *point* instead of a ball, then on turning the machine and exhausting the air, the small brush of light which first makes its appearance on the point gradually enlarges, varying in appearance and becoming more diffused as the air becomes more rarefied, until at length the whole of the receiver is filled with a beautiful and varying light, producing an effect which is pleasing in the highest degree. (*Singer.*)

Fig. 60.



(111) *Electricity of effluent steam.* Under the head of *frictional* Electricity must be included this very remarkable source of electrical development, which in the hands of Messrs. Faraday, Armstrong, Ibbetson, and others, has led to the construction of electrical machines compared to which even the most powerful glass machines hitherto constructed are but as pigmies.

The first account we have of an observation on the Electricity of a jet of steam while issuing from a boiler is contained in a letter addressed

to Professor Faraday, by H. S. Armstrong, Esq. (*Phil. Mag.* vol. xvii.)

It appears that the phenomenon was first noticed by the engine-man entrusted with the care of a steam engine at Sedgehill, about six miles from Newcastle: it happened that the cement, by which the safety-valve was secured to the boiler had a crack in it, and through this fissure a copious horizontal jet of steam continually issued. Soon after this took place, the engine-man having one of his hands accidentally immersed in the issuing steam, presented the other to the lever of the valve, with the view of adjusting the weight, when he was greatly surprised by the appearance of a brilliant spark, which passed between the lever and his hand, and was accompanied by a violent wrench in his arms, wholly unlike what he had ever experienced before. The same effect was repeated when he attempted to touch any part of the boiler, or any iron work connected with it, provided his other hand was exposed to the steam. He next found that while he held one hand in the jet of steam, he communicated a shock to every person whom he touched with the other, whether such person was in contact with the boiler, or merely standing on the brickwork which supported it; but that a person touching the boiler, received a much stronger shock than one who merely stood on the bricks.

(112) In following up these experiments, Mr. Armstrong provided himself with a brass plate having a copper wire attached to it, which terminated in a round brass knob. When this plate was held in the steam, by means of an insulated handle, and the brass knob brought within about a quarter of an inch from the boiler, the number of sparks which passed in a minute was from sixty to seventy, and when the knob was advanced about one-sixteenth of an inch nearer to the boiler the stream of Electricity became quite continuous. The greatest distance between the knob and the boiler, at which a spark would pass from one to the other, was fully an inch. A Florence flask, coated with brass filings on both surfaces, was charged to such a degree with the sparks from the knob, as to cause a spontaneous discharge through the glass,—and several robust men received a severe shock from a small Leyden jar charged by the same process. The strength of the sparks was quite as great when the knob was presented to any conductor communicating with the ground, as when it was held to the boiler.

(113) A long and well-conducted series of experiments was made by Mr. Armstrong, on the Electricity evolved under these peculiar circumstances.* By standing on an insulated stool, and holding with one

* See L. and E. Phil. Mag. vol. xvii. pp. 370, 452; vol. xviii. pp. 50, 133, 328; vol. xix. p. 25; vol. xx. p. 5; vol. xxii. p. 1. See also papers on the same subject by

hand a light iron rod immediately above the safety-valve of a locomotive engine, while the steam was freely escaping, and then advancing the other hand towards any conducting body, he obtained sparks of an inch in length; when the rod was held five or six feet above the valve, the length of the sparks was two inches; and when a bunch of pointed wires, attached to the rod, was held points downwards in the issuing steam, sparks *four inches long* were drawn from a round knob, on the opposite extremity of the iron rod. On insulating the boiler, large and brilliant *negative* sparks an inch long were drawn from it—the Electricity of the steam being positive.

(114) A small boiler was constructed by Mr. Armstrong—it was arranged on a stove which was insulated; when the rate of evaporation was about a gallon in an hour, and the pressure in the boiler 100 lbs. on the square inch, by connecting the knob of a Leyden phial with the boiler or stove, he was able to give it a charge, and he found that Electricity could be collected in much greater abundance from the evaporating vessel than from the issuing steam. The Electricity of the steam was generally positive, that of the insulated boiler being negative; occasionally, however, these conditions were reversed, and after the boiler had been in use for some time, positive Electricity rarely appeared in the jet, even when circumstances were most favourable to its development. No alteration was effected by washing out the boiler with water, but when it was washed with solution of *potash* or *soda*, the *positive* condition of the steam jet was restored, and by dissolving a little potash in the water from which the steam was generated, the quantity of Electricity was amazingly increased; on the other hand, when a small quantity of *nitric acid*, or *nitrate of copper*, was added to the water, the Electricity of the steam became negative.

(115) Subsequent experiments led Mr. Armstrong to the conclusion that the excitation of Electricity takes place at the point where the steam is subjected to friction; and, in a paper subsequently read before the Royal Society by Professor Faraday, it was shown that the steam itself has nothing to do with the phenomenon. By means of a suitable apparatus, Faraday found that Electricity is never excited by the passage of pure steam, and is manifested only when water is at the same time present; and hence he concludes that it is altogether the effect of the friction of globules of water against the sides of the opening, or against the substances opposed to its passage, as the water is rapidly moved onwards by the current of steam. Accordingly, it was found to be increased in quantity by increasing the pressure and impelling force of

Mr. Pattinson, vol. xvii. pp. 375, 457; and by Dr. Schafhaeutl, vol. xvii. p. 449; vol. xviii. pp. 14, 95, 265.

the steam. The immediate effect of this friction was, in all cases, to render the steam or water positive, and the solids, of whatever nature they might be, negative. In certain circumstances, however, as when a wire is placed in the current of steam, at some *distance from the orifice* whence it has issued, the solid exhibits the positive Electricity already acquired by the steam, and of which it is then merely the recipient and the conductor. In like manner the results may be greatly modified by the shape, the nature, and the temperature of the passage through which the steam is forced. Heat, by preventing the condensation of the steam into water, likewise prevents the evolution of Electricity, which again speedily appears by cooling the passages, so as to restore the water which is necessary for the production of that effect. The phenomena of the evolution of Electricity, in these circumstances, are dependent also on the quality of the fluid in motion, more especially in relation to its conducting power. Water will not excite Electricity unless it be pure: the addition of any soluble salt or acid, even in minute quantity, is sufficient to destroy this property. The addition of oil of turpentine, on the other hand, occasions the development of Electricity of an opposite kind to that which is excited by water; and this Faraday explains, by the particles and minute globules of the water having each received a coating of oil, in the form of a thin film, so that the friction takes place only between that external film and the solids, along the surface of which the globules are carried. A similar but more permanent effect is produced by the presence of olive oil, which is not, like oil of turpentine, subject to rapid dissipation. Similar results were obtained when a stream of compressed air was substituted for steam in these experiments. When moisture was present, the solid exhibited negative, and the stream of air positive Electricity; but when the air was perfectly dry, no Electricity of any kind was apparent.

(116) Mr. Armstrong subsequently (*Phil. Mag.* vol. xxii. p. 1) confirmed the conclusion, that the excitation of Electricity takes place at the point where the steam is subjected to friction, and described several improvements in his apparatus by which the energy of the effects was amazingly increased. By means of a boiler furnished with a stop cock and discharging jet of peculiar construction, he produced effects upwards of seven times greater than those from a plate electrical machine of three feet in diameter, worked at the rate of seventy revolutions per minute. This boiler was a wrought iron cylinder, with rounded ends, and measured three feet six inches in length, and one foot six inches in diameter. It rested on an iron frame, containing the fire, and the whole apparatus was supported on glass legs to insulate it. It was found much more convenient and effectual to collect Electricity from the boiler than from the steam cloud, but, in order to obtain the highest effect from the

boiler, the Electricity of the steam must be carried to the earth by means of proper conductors.

(117) In Mr. Pattinson's experiments on one of the locomotive engines belonging to the Newcastle and Carlisle Railway, sparks *four inches* long were given off from the person of an individual standing on an insulating stool, and holding a copper rod, terminated by sharp-pointed wires, in the current of steam, blowing forcibly out of the safety-valve at a pressure of 52 lbs. per inch. The Electricity was ascertained to be positive. It is certainly, as Mr. Pattinson observes, a novel and curious light in which to view the splendid locomotive engine in its rapid passage along the railway line, viz., that of an enormous electrical machine,—the steam analogous to the glass plate of an ordinary machine, and the boiler to the rubber; while torrents of Electricity might continually be collected, by properly disposing conductors in the escaping steam.

(118) Shortly after these experiments were made the directors of the Polytechnic Institution determined on constructing a machine on a large scale for the purpose of producing Electricity by the escape of steam, and under the superintendence of Mr. Armstrong, assisted by Captain Ibbetson, the "Hydro-Electric Machine" was finished and placed in the theatre of the institution, where by its extraordinary power it soon excited the astonishment of all who beheld it. The machine consists of a cylindrical-shaped boiler, similar in form to a steam-engine boiler, constructed of iron plate ¼ inch thick; its extreme length is 7 feet 6 inches, 1 foot of which being occupied by the smoke chamber, makes the actual length of the boiler only 6 feet 6 inches; its diameter is 3 feet 6 inches. The furnace and ash-hole are both within the boiler; when it is required entirely to exclude the light a metal screen is readily placed over these; by the side of the door is the water-gauge and feed-valve. On the top of the boiler, and running nearly its entire length, are forty-six bent iron tubes, terminating in jets having peculiar shaped apertures, and formed of partridge wood, which experience has shown Mr. Armstrong to be the best for the purpose; from these the steam issues—the tubes spring from one common pipe, which is divided in the middle and communicates with the boiler by two elbows: by this contrivance the steam is admitted either to the whole or part of the tubes, the steam being shut off or admitted by raising or lowering the two lever handles placed in the front of the boiler. Between the two elbows is placed the safety-valve for regulating the pressure, and outside them on one side is a cap covering a jet employed for illustrating a certain mechanical action of a jet of steam, and on the other a loaded valve for liberating the steam when approaching its maximum degree of pressure. At the further

extremity of the boiler is the funnel-pipe or chimney, so contrived that, by the aid of pulleys and a balance weight, the upper part can be raised and made to slide into itself (similar to a telescope), so as to leave the boiler entirely insulated. To prevent as much as possible the radiation of heat, the boiler is cased in wood, and the whole is supported on six stout glass legs 3½ inches diameter, and 3 feet long. In front of the jets, and covering the flue for conveying away the steam, is placed a long zinc box, in which are fixed four rows of metallic points for the purpose of collecting the Electricity from the ejected vapour, and thus prevent its returning to restore the equilibrium of the boiler the box is so contrived that it can be drawn out or in, so as to bring the points nearer or further from the jets of steam; the mouth or opening can also be rendered wider or narrower: by these contrivances the power and intensity of the spark is greatly modified. A ball and socket-joint, furnished with a long conducting rod, has been added to the machine, so that by its aid the Electricity can be readily conveyed to the different pieces of apparatus used to exhibit various phenomena. The pressure at which the machine is usually worked is 60 lbs. on the square inch. As it is now fully established that the Electricity of the hydro-electric machine is occasioned by the friction of the particles of water (115), the latter may be regarded as the glass plate of the common electrical machine, the partridge wood as the rubber, and the steam as the rubbing power. The Electricity produced by this engine is not so remarkable for its high intensity as for its enormous quantity. The maximum spark obtained by Mr. Armstrong in the open air was 22 inches; the extreme length under present circumstances has been 12 or 14 inches; but the large battery belonging to the Polytechnic Institution, exposing nearly 80 feet of coated glass which, under favourable circumstances, was charged by the large plate machine 7 feet in diameter in about 50 seconds, is commonly charged by the hydro-electric engine in 6 or 8 seconds. The sparks which pass between the boiler and a conductor are exceedingly dense in appearance: and, especially when short, more resemble the discharge from a coated surface than from a prime conductor. They not only ignite gunpowder, but even inflame paper and wood shavings when placed in their course between two points.

In the 151st number of the *Philosophical Magazine*, a series of electrolytic experiments made with this machine are described by Mr. Armstrong: true polar decomposition of water was effected in the clearest and most decisive manner, not only in one tube, but in ten different vessels arranged in series, and filled respectively with distilled water, water acidified with sulphuric acid, solution of sulphate of soda, tinged blue and red, solution of sulphate of magnesia, &c.,

&c., and the gases were obtained in sufficient quantities for examination.

The following curious experiments are likewise described:—two glass vessels containing pure water were connected together by means of wet cotton; on causing the electric current to pass through the glasses, the water rose above its original level in the vessel containing the negative pole, and subsided below it in that which contained the positive pole, indicating the transmission of water in the direction of a current flowing from the positive to the negative wire.

Two wine glasses were then filled nearly to the edge with distilled water, and placed about 4-10ths of an inch from each other, being connected together by a wet silk thread of sufficient length to allow a portion of it to be coiled up in each glass. The negative wire, or that which communicated with the boiler, was inserted in one glass, and the positive wire, or that which communicated with the ground, was placed in the other. The machine being then put in action, the following singular effects presented themselves:—

1st,—A slender column of water, inclosing the silk thread in its centre, was instantly formed between the two glasses, and the silk thread began to move from the negative towards the positive pole, and was quickly all drawn over and deposited in the positive glass.

2nd,—The column of water after this continued for a few seconds suspended between the glasses as before, but without the support of the thread; and when it broke the Electricity passed in sparks.

3rd,—When one end of the silk thread was made fast in the negative glass the water diminished in the positive glass and increased in the negative one, showing apparently that the motion of the thread, when free to move, was in the reverse direction of the current of water.

4th,—By scattering some particles of dust upon the surface of the water, it was soon perceived by their motions that there were two opposite currents passing between the glasses, which, judging from the action upon the silk thread in the centre of the column, as well as from other less striking indications, were concluded to be *concentric*, the inner one flowing from negative to positive, and the outer one from positive to negative. Sometimes that which was assumed to be the outer current was not carried over into the negative glass, but trickled down outside of the positive one; and then the water, instead of accumulating as before in the negative glass, diminished both in it, and in the positive glass.

5th,—After many unsuccessful attempts Mr. Armstrong succeeded in causing the water to pass between the glasses, without the intervention of a thread for a period of several minutes, at the end of which time he could not perceive that any material variation had taken place in the

quantity of water contained in either glass. It appeared therefore, that the two currents were *nearly*, if not *exactly* equal, while the inner one was not retarded by the friction of the thread. Mr. Armstrong likewise succeeded in coating a small silver coin with copper; in deflecting the needle of a galvanometer, between 20° and 30°; and in making an electro-magnet by means of the Electricity from this novel machine.

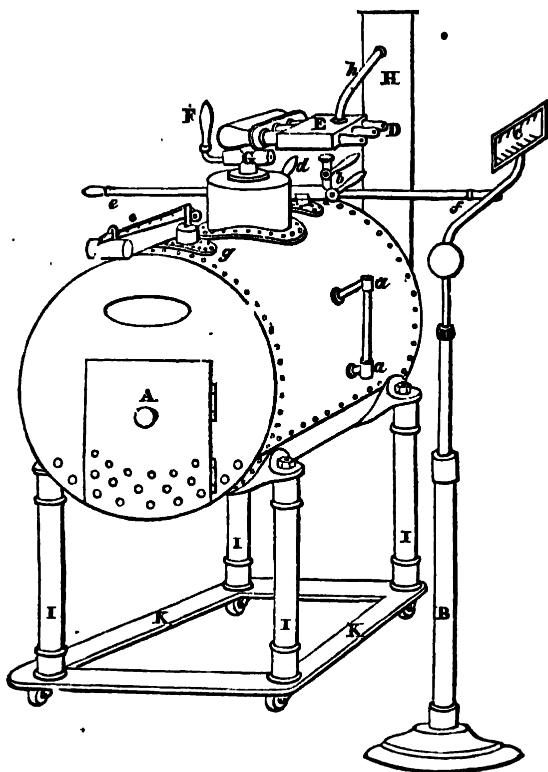
(119) Extraordinary as is the power of the Polytechnic machine, it was afterwards entirely eclipsed by a similar apparatus constructed at Newcastle under the direction of Mr. Armstrong, and sent out to the United States of America. In the arrangement of this machine, the boiler of which is not larger than that at the Polytechnic Institution, Mr. Armstrong introduced certain improvements suggested by the working of the latter, and which had reference to those parts of the apparatus more immediately concerned in the production of the Electricity, viz., "*the escape apertures and the condensing pipes.*" It was found to be a matter of extreme nicety so to adjust the quantity of water deposited in the condensing pipes as to obtain the maximum excitation of Electricity. If on the one hand there be an excess of water, then two results will ensue, each tending to lessen the Electricity produced. 1°. The mean density of the issuing current of steam and water is increased, which causes the velocity of efflux and consequent energy of the friction to be diminished; and 2°. The ejected steam cloud is rendered so good a conductor by the excess of moisture that a large proportion of the Electricity manifested in the cloud retrocedes to the boiler, and neutralizes a corresponding proportion of the opposite element. On the other hand, if the quantity of water be too small, then, although each particle of water may be excited to the fullest extent, the effect is rendered deficient in consequence of the insufficient number of aqueous particles which undergo excitation. In the Polytechnic arrangement the condensation of the steam in the tubes is effected by contact of the external air, and when the density of the steam in the boiler is diminished rapidly they do not cool down with sufficient rapidity to condense the requisite quantity of water. To remedy this defect in the American machine, Mr. Armstrong adopted a method of condensing by the application of cold water: a number of cotton threads were suspended from each condensing pipe into a trough of water from which by capillary attraction just as much water was lifted as was required for the cooling of the pipe, since it was easy by increasing or diminishing the quantity of cotton to increase or diminish the supply of cold water; and this method of keeping down the temperature proved so effective that two or three times the number of jets that were before used could now be employed. The number in the American machine was 140, ranged in two horizontal rows, one above

the other, on the same side of the machine. The sparks obtained, though not longer than those upon the London machine when it stood in the open air, succeeded each other *with three or four times* the rapidity, and even under unfavourable circumstances charged a Leyden battery consisting of thirty-six jars, containing thirty-three feet of coated surface, to the utmost degree that the battery would bear, upwards of sixty times in a minute, being equivalent to charging nearly 2000 feet of coated surface in one minute, which is at least *twenty times* greater than the utmost effect that could be obtained from the largest glass electrical machine ever constructed.

(120) The action of the hydro-electric machine is greatly influenced by the nature of the water from which the steam is generated, which should be as pure as possible in order that no impurities should pass from the boiler to the steam passages. It is indeed perfectly surprising how extremely small an admixture of some substances has the effect of reversing the electrical state of the boiler and steam cloud. When a piece of cotton was steeped in a solution of acetate of lead, and inserted in the condensing pipe, Mr. Armstrong found that the Electricity of the steam, which in general was positive, was changed to *negative*. Again, when the conducting pipe is of brass instead of iron the steam cloud is *positively* electrified the same as in ordinary cases; but if the pipe previously to being used has been immersed in very dilute nitric acid, then negative Electricity instead of positive will be evolved by the steam cloud, notwithstanding that the pipe may have been washed with clean water subsequently to its immersion in the acid, nor does the pipe re-gain the condition necessary for the production of a powerful development of positive Electricity in the steam, till it has been thoroughly washed out with an alkaline solution. Mr. Armstrong found also that the effects were singularly influenced by the material of which the condensing pipe is formed; thus, glass, lead, tin, copper, and iron, are each effective in a different degree, the variation, as he believes, being in all these cases due to minute quantities of extraneous matter acquired by the condensed water acting chemically or mechanically upon the material of the pipes.

(121) Messrs. Watson and Lambert of Newcastle, who built both the Polytechnic and the American machines, construct "hydro-electric machines" of all sizes; they are mounted on carriages so as to be readily moved about, and they constitute very elegant pieces of electrical apparatus. One of these machines is shown in Fig. 61. The boiler is 2 feet 6 inches in length, and 1 foot 2 inches in diameter; A is the door of the fire-place; B C, the conductor for collecting Electricity from the steam; B, a glass insulating stem; C, the collecting points; D, the escape tubes and jets; E, the condensing vessel enclosing the iron pipes by which the steam is conveyed to the jets. The lower part

Fig. 61.



of the condensing vessel contains water which nearly reaches the lower side of the steam pipes; from the latter are suspended filaments of cotton, which dip into the water, and by capillary action raise just sufficient to cause, by its action on the pipes, a condensation of the passing steam into the requisite quantity of water for rubbing against the jet. F G is the cock for letting off the steam; H, the chimney; I I, the insulating glass pillars; K K, the frame moving on castors; *a a*, the water gauge; *f e*, condensing pipes for showing the effect of impregnating the ejected water with extraneous substances, and for exhibiting two jets of steam simultaneously issuing from the boiler in opposite states of Electricity; *b*, the cock for introducing extraneous matter; *c d*, cocks for admitting steam to the pipes; *g*, the safety-valve; *h*, the escape pipe for the vapour of the condensing tube. The fuel is charcoal. When in good working order a machine of the above size will produce, according to the makers, as much Electricity as three 30-inch plate glass machines.

Mr. Walker (*Elect. Mag.* vol. i. p. 126) describes certain experiments which were made in order to contrast the effects of the great Polytechnic hydro-electric and glass electric machines, the plate of the latter being seven feet in diameter. On placing the large battery on an insulating stool between the prime conductor and the boiler, and connecting the inner coating with the former, and the outer with the latter, he several times failed in communicating a charge: on reversing connexions it was accomplished more readily, though in far longer time than would have been required by the boiler alone. Again, when the *aurora* obtained by passing the Electricity from the prime conductor through an exhausted tube 4 or 5 feet in length, was contrasted with that produced from the Electricity of the boiler passing through the same tube, the latter was, by many degrees, more brilliant; but when the boiler was connected with one end of the tube, as it stood on an insulating stool, and the prime conductor with the other, the brilliancy greatly diminished. It was at first thought that if the earth in its *normal* condition could supply to the boiler Electricity equivalent to the production of a certain effect in a certain time, the prime conductor in its positively charged state would produce a greater effect. The actual diminution of effect was, however, on consideration connected with known laws, for, as the maximum supply of positive Electricity which the conductor could furnish was at most not a *fourth* of that required by the negative boiler, and as the supply from the earth was unlimited, the whole equilibrium was restored in the one case and only a portion of it in the other.

(122) Peltier (*L'Institut*, Aug. 7, 1844) does not adopt the theory that friction is the cause of the wonderful development of Electricity in the hydro-electric machine; he refers it to chemical decomposition. Every chemical action produces an electrical phenomenon, and every solution however diluted it might be, being a chemical combination, it follows that in the act of evaporation above a solution, the combined element, by separating, produces the converse chemical action, that of decomposition, and hence an electrical phenomenon with signs contrary to the act of combination. The reason why electrical phenomena are not manifested during slow evaporation, or even during the boiling of water under simple atmospheric pressure, is, according to Peltier, that the vapour is not separated with sufficient suddenness from the rest of the liquid, to carry away and retain the Electricity of the chemical action of its separation, the neutralization by return being made with too much facility in the moist atmosphere touching the surface of the liquid. A boiler is but another means of obtaining vapour at high tension, as it suddenly separates from the liquid; but

the form which we are obliged to give it is very much opposed to the free liberation of the Electricity, so that we obtain comparatively very small quantities of what is really produced. The quantities depend not only on the internal pressure, but also on the *jets*, which oppose or facilitate the neutralization by return. Hence it is, that powerful locomotives have been seen to present but feeble electrical results, while a small boiler may give them on a considerable scale; when a saline solution is projected into a red-hot platina capsule, it becomes insulated from the vessel, and its evaporation goes on slowly, the temperature of the liquid never reaching the boiling point of water. As however, the concentration proceeds, particles of saline matter become deposited on the sides of the vessel, and establish partial contacts between the liquid and the metal, these particles of liquid are thus suddenly transformed into elastic vapour, the tension of which is proportionate to the temperature at which it has been formed, and it is this vapour alone that preserves the Electricity due to its passage from the liquid to the gaseous state. The higher the temperature of the capsule, the greater the quantity of Electricity preserved: below 230° Fah. Peltier obtained no signs of Electricity. When in this experiment pure water is substituted for the saline solution, no Electricity is obtained, because no contact takes place between the liquid and the metal, until the temperature of the latter has descended to about 230°, the evaporation then goes on too slowly to place an insulating space between the vapour and the liquid, and the electric phenomenon is completed by returning to a state of neutralization, by means of the conductibility of the column of vapour. To obtain Electricity from high pressure boilers, the conditions are, 1st, an internal pressure of several atmospheres; 2nd, that the vapour shall be accompanied by a projection of water; and Peltier's view is, that the Electricity is not brought out from the boiler by the escaping vapour, but that it arises from the vapour of the drops of water that are projected at a high temperature, a portion of which is immediately vaporized.

(123) Some interesting experiments are related by Peltier in illustration of his view. By elevating an Electrometer immediately underneath the column of vapour, given off by a locomotive engine in motion, he found that the electrical signs were more considerable as the rapidity of the train increased, they diminished as the velocity diminished, and when the train was near stopping, all signs of Electricity disappeared. This he explains by referring the electrical phenomena to the quick separation of the liquid and vapour at the moment of its formation; when the train was moving quickly

the column of vapour was rapidly broken up into particles; as the velocity diminished, the column became more united, and there was therefore less electrical development. The more rare the globular vapour, the greater the signs of *positive* Electricity; the Electricity of an opaque column was on the contrary *negative*: it was noticed also, that the condensation of the vapour on the ball of the Electroscope suddenly changed the Electricity from *positive* to *negative*, and that while the head of the column of vapour was *positive* the tail was *negative*, the intermediate portions alternating from positive to negative according to the velocity of the train, the quantity of the prevailing vapours, the rapidity of the evaporation, and the state of the sky.

(124) *Disruptive discharge.*—We will now inquire a little more minutely into the nature of electric discharge, which has been made by Faraday the subject of close investigation (*Experimental Researches*, 13th and 14th series). The discharge which takes place between two conducting surfaces is termed *disruptive*: it is the limit of the influence which the intervening air or dielectric exerts in resisting discharge: all the effects prior to it are inductive (82), and it consequently measures the conservative power of the dielectric. It occurs not when all the particles have attained to a certain degree of tension; but when that particle which is most affected has been exalted to the subverting or turning point, all must then give way, since they are linked together, as it were, by the influence of the constraining force, and the breaking down of one particle must, of necessity, cause the whole barrier to be overturned. In every case, the particles, amongst and across which the discharge suddenly breaks, are displaced—the path of the spark depending upon the degree of tension acquired by the particles in the line of discharge.

(125) The spark may be considered then, as a discharge, or lowering of the polarized inductive state of many dielectric particles by a particular action of a few of the particles occupying a very small and limited space: all the previously polarized particles returning to their first or normal condition in the inverse order in which they left it, and uniting their powers meanwhile, to produce, or rather to continue, the discharge effect in the place where the subversion of force first occurred.

We have given this explanation in the words employed by Faraday, that no misconception of his meaning may arise. He is of opinion that a peculiar temporary state is assumed by the particles situated where discharge occurs; that they have all the surrounding forces thrown upon them in succession, and that they are not merely pushed apart; that the whole terminates by a discharge of the powers

by some, as yet, unknown operation, the ultimate effect being exactly as if a metallic wire had been put into the place of the discharging particles.

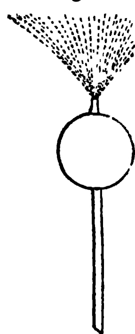
(126) The electric spark presents different appearances when taken in different elastic media. In air, they have, when obtained with brass balls, a well-known intense light, and bluish colour, with frequently faint or dark parts in their course, when the quantity of Electricity passing is not great. In *nitrogen* they are very beautiful, having the same general appearance as in air, but more colour, of a purple or bluish character; and Faraday thought that they were remarkably sonorous. In *oxygen* they are whiter, but not so brilliant as in common air. In *hydrogen* they are of a fine *crimson* colour, and have very little sound in consequence of the physical condition of the gas. In *carbonic acid gas* they have the same general appearance as in air, but are remarkably irregular. Sparks can be obtained under similar circumstances, much longer than in air, the gas showing a singular readiness to pass the discharge. In *muriatic acid gas*, when dry, they are nearly white, and always bright throughout. In *coal gas* they are sometimes green and sometimes red, and occasionally one part is green and another red. Black parts also occur very suddenly in the line of the spark, i. e. they are not connected by any dull part with bright portions, but the two seem to join directly one with the other.

It is the impression of Faraday that these varieties of character are due to a direct relation of the electric powers to the particles of the dielectric through which the discharge occurs, and are not the mere results of a casual ignition, or a secondary kind of action of the Electricity upon the particles which it finds in its course and thrusts aside in its passage. It was remarked by M. Fusinieri, that when a spark takes place between a surface of silver and another of copper, a portion of silver is carried to the copper, and of copper to the silver; and Dr. Priestley observed, that if a metallic chain be laid upon a sheet of paper, or a plate of glass, and a strong discharge sent through it, spots will be produced upon it of the size and colour of each link, parts of which will be found to be fused into the substance of the glass.

(127) *The Electrical Brush.*—The phenomenon of the electrical brush has been shown by Professor Wheatstone to consist of successive *intermitting* discharges, although it appears continuous. If an insulated conductor, connected with the positive conductor of an electrical machine, have a metallic rod 0·3 of an inch in diameter, projecting from it outwards from the machine, and terminated by a rounded end or small ball, it will generally give good brushes; or if

the machine be not in good action, then many ways of assisting the formation of the brush may be resorted to; thus, the hand, or any large conducting surface, may be approached towards the termination to increase the inductive force; or the termination may be smaller, and of badly conducting matter, as wood: or sparks may be taken between the prime conductor and the secondary conductor, to which the termination giving brushes belongs; or, (which gives to the brushes exceedingly fine characters and great magnitude,) the air around the termination may be rarefied, more or less, either by heat or the air-pump, the former favourable circumstances being also continued. When obtained by a powerful machine, or a ball about 0·7 of an inch in diameter at the end of a long brass rod, attached to the positive prime conductor, it has the general appearance, as to form, represented in Fig. 62. A short conical bright part or root appears at the middle part of the ball, projecting directly from it, which at a little distance from the ball breaks out suddenly into a wide brush of pale ramifications, having a quivering motion, and being accompanied at the same time with a low dull chattering sound. The general brush is resolvable into a number of individual brushes, each of which is the result of a single discharge—each is instantaneous in its existence, and each appeared to Faraday to have the conical root complete. The sound is due to the recurrence of the noise of each separate discharge, which, happening at intervals nearly equal, under ordinary circumstances causes a definite note to be heard, which, rising in pitch with the increased rapidity and regularity of the intermitting discharges, gives a ready and accurate measure of the intervals, and so may be used in any case when the discharge is heard, even though the appearances may not be seen, to determine the element of *time*.

Fig. 62.



(128) The brush is, in reality, a discharge between a bad, or a non-conductor, and either a conductor or another non-conductor. It is explained by Faraday on the principles of induction, which, taking place between the end of an electrified rod and the walls of a room, across the dielectric air, polarizes the particles of air; those which are nearest to the end of the wire being most polarized, and those situated in sections across the lines of inductive force towards the walls being least polarized. In consequence of this state, the particle of air at the end of the wire is at a tension that will immediately terminate in discharge, while in those even only a few inches off the tension is still beneath that point. When the discharge takes place,

the particle of air in the immediate vicinity of the rod instantaneously resumes its polarized state, the wire itself regaining *its* electrical state by induction; the polarized particle of air exerts a distinct inductive act towards the further particles, and thus a progressive discharge from particle to particle takes place. The difference between the brush discharge and the spark is, that in the former discharge begins at the root (127), and extending itself in succession to all parts of the single brush, continues to go on at the root and the previously-formed parts, until the whole brush is complete; then, by the fall in intensity and power at the conductor, it ceases at once in all parts, to be renewed when that power has risen again to a sufficient degree; but in the latter, the particles in the line of discharge being, from the circumstances, nearly alike in their intensity of polarization, suffer discharge so nearly at the same moment as to make the time quite insensible to us. Mr. Wheatstone found that the *brush* generally had a sensible duration, but he could detect no such effect in the spark.

(129) According to Faraday, the *brush* may be considered as a spark to air; a diffusion of electric force to matter, not by *conduction*, but by disruptive discharge; a dilute spark, which, passing to very badly conducting matter, frequently discharges but a small portion of the power stored up in the conductor: for as the air charged reacts on the conductor, whilst the conductor, by loss of Electricity, sinks in its force, the discharge quickly ceases, until, by the dispersion of the charged air, and the renewal of the excited conditions of the conductor, circumstances have risen up to their first effective condition, again to cause discharge, and again to fall and rise.

(130) By making a small ball positive by a good electrical machine with a large prime conductor, and approaching a large uninsulated discharging ball towards it, very beautiful variations from the spark to the brush may be obtained. In Fig. 62 the general appearance of a good brush is exhibited; but if the hand, a ball, or any knobbed conductor be brought near, the extremities of the coruscations turn towards it and each other, and the whole assumes various forms, according to circumstances, as shown in Figs. 63, 64, 65. The curvature of these ramifications illustrates, in a beautiful manner, the curved form of the lines of inductive force existing previous to discharge, in the same manner as iron filings strewed on a sheet of paper placed over a magnet represent magnetic curves; and the phenomena are considered by Faraday as constituting additional and powerful testimony in favour of induction through dielectrics in curved lines (78), and of the lateral relation of these lines by an effect equivalent to a repulsion producing divergence, or, as in the cases figured, the bulging form.

Fig. 63.

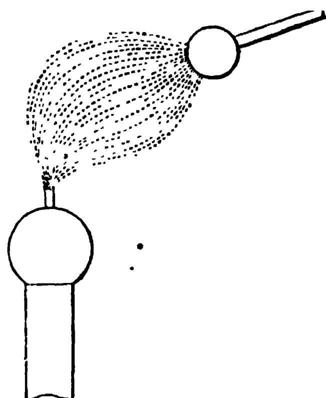


Fig. 64.

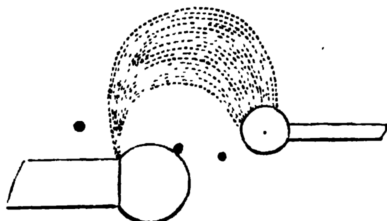
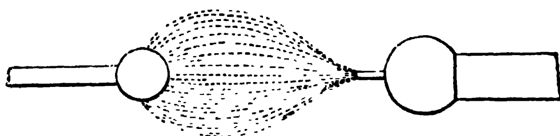


Fig. 65.



(131) Discharge in the form of a brush is favoured by rarefaction of the air, in the same manner and for the same reason as discharge in the form of a spark. It may be obtained not only in air and gases, but also in much denser media. Faraday procured it in oil of turpentine, but it was small, and produced with difficulty. He also found that, like the spark, the brush has *specific characters* in different gases, indicating a relation to the particles of these bodies, even in a stronger degree than the spark. In *nitrogen*, brushes were obtained with far greater facility than in any other gas; and when the gas was rarefied, they were exceedingly fine in form, light, and colour; in oxygen, on the other hand, they were very poor.

(132) The peculiar characters of nitrogen in relation to the electric discharge must, Faraday observes, have an important influence over the *form* and even the *occurrence of lightning*, being that gas which most readily produces coruscations, and by them extends discharge to a greater distance than any other gas tried, it is also that which constitutes four-fifths of our atmosphere; and as in atmospheric electrical phenomena, one, and sometimes both the inductive forces are resident on the particles of the air, which, though probably affected as to conducting power by the aqueous particles in it, cannot be considered as a good conductor; so the peculiar power possessed by nitrogen to originate and effect discharge in the form of a brush or of ramifications, has probably an important relation to its electrical service in nature,

as it most seriously affects the character and condition of the discharge when made.

(133) The characters of the luminous appearances at the ends of wires charged positively and negatively are represented in Fig. 44. Faraday has paid considerable attention to the difference of discharge at the positive and negative conducting surfaces. According to his observations, the effect varies exceedingly under different circumstances. It is only with bad conductors, or metallic conductors charged intermittingly, or otherwise controlled by collateral induction, that the brush and star are to be distinctly distinguished: for if metallic points project freely into the air, the positive and negative lights differ very little in appearance, and the difference can be observed only upon close examination. If a metallic wire with a rounded termination in free air, be used to produce the brushy discharge, then the brushes obtained when the wire is charged negatively are very poor and small by comparison with those produced when the charge is positive: or, if a large metal ball connected with the electrical machine be charged *positively*, and a fine uninsulated point be gradually brought towards it, a star appears on the point when at a considerable distance, which, though it becomes brighter, does not change its form of a star until it is close up to the ball; whereas, if the ball be charged negatively, the point at a considerable distance has a star on it as before; but when brought nearer, (within about 1½ inch,) a brush forms on it, extending to the negative ball; and when still nearer, (at ⅛ of an inch distance,) the brush ceases, and bright sparks pass.

(134) The successive discharges from a rounded metallic rod 0·3 of an inch in diameter, projecting into air when charged negatively, are very rapid in their recurrence, being seven or eight times more numerous in the same period than those produced when the rod is charged positively to an equal degree; but each brush carries off far less electric force in the former case than in the latter. Faraday also perceived a very important variation of the relative forms and conditions of the positive and negative brush, by varying the dielectric in which they were produced. The difference, indeed, was so great, as to point out a specific relation of this form of discharge to the particular gas in which it takes place, and opposing the idea that gases are but obstructions to the discharge, acting one like another, and merely in proportion to their pressure. Generally speaking, when two similar small conducting surfaces equally placed in air, are electrified, one positively and the other negatively, that which is negative can discharge to the air *at a tension a little lower* than that required for the positive ball, and when discharge does take place,

much more passes at each time from the positive than from the negative surface.

(135) *Glow discharge.*—When a fine point is used to produce disruptive discharge from a positively charged conductor, the brush gives place to a quiet phosphorescent continuous glow, covering the whole of the end of the wire, and extending a small distance into the air. Occasionally this glow takes the place of the brush, when a rounded wire 0·3 of an inch in diameter is used, and the finer the point the more readily is it produced: thus, *diminution of the charging surface* produces it: increase of power in the machine tends to it, and it is surprisingly favoured by rarefaction of the air. A brass ball 2½ inches in diameter, when made positively inductric (82) in an air-pump receiver, becomes covered with a glow over an area of two inches in diameter, when the pressure is reduced to 4·4 inches of mercury. By a little adjustment, Faraday succeeded in covering the ball all over with this light; using a brass ball 1·25 inches in diameter, and making it inducteously positive by an inductric negative point, the phenomena at high degrees of rarefaction were exceedingly beautiful. The glow came over the positive ball, and gradually increased in brightness, until it was at last very luminous, and it stood up like a low flame, half an inch or more in height. On touching the sides of the glass jar, this lambent flame was affected, assumed a ring form, like a crown on the top of the ball, appeared flexible, and revolved with a comparatively slow motion, i. e., about four or five times in a second.

(136) The glow is always accompanied by a wind proceeding either directly out from the glowing part, or directly towards it. Faraday was unable to analyse it into visible elementary intermitting discharges, nor could he obtain the other evidence of intermitting action —namely, an audible sound (127). It is difficult to produce it at common pressures with *negative* wires, even on fine points, though in rarefied air the negative glow can easily be obtained.

(137) All the effects tend to show that *glow* is due to a continuous charge or discharge of air; in the former case being accompanied by a current from, and in the latter case by one to, the place of the glow. As the surrounding air comes up to the charged conductor, on attaining that spot at which the tension of the particles is raised to the sufficient degree, it becomes charged, and then moves off by the joint action of the forces to which it is subject, and at the same time that it makes way for other particles to come and be charged in turn, actually helps to form that current by which they are brought into the necessary position. Thus, through the regularity of the forces, a constant and quiet result is produced, and that result is, the

charging of successive portions of air, the production of a current and of a continuous glow.

(138) By aiding the formation of a current at its extremity, the brush at the termination of a rod may be made to produce a glow, and on the other hand by affecting the current of air, by sheltering the point from the approach of air, it is not difficult to convert the glow into brushes. The *glow* is assisted by those circumstances which tend to facilitate the charge of the air by the excited conductor, the *brush* by those which tend to resist the charge of the same; and those which favour intermitting discharge in a more exalted degree favour the production of the *spark*. Thus the transition from the one to the other may be established in various ways: by rarefying the air, by removing large conducting surfaces from the neighbourhood of a glowing termination, or by presenting a sharp point towards it, we help to sustain the glow; and by condensing the neighbourhood of a discharging ball, or by presenting the hand gradually towards it, we convert the glow into the brush or spark.

(139) Before proceeding further, it may be useful to give a general summary of the views of Faraday relating to induction. His theory is not intended to offer anything new as to the nature of the electric force or forces, but only as to their distribution. It undertakes to state *how* the powers are arranged, to trace them in their general relations to the particles of matter, to determine their general laws, and the specific differences which occur under these laws.

(140) The theory assumes:

1°. That all the *particles*, whether of insulating or conducting matter, are, as wholes, conductors.

2°. That not being in their normal state *polar*, they can become so by the influence of neighbouring charged particles, the polar state being developed at the instant, exactly as in an insulating conducting *mass* consisting of many particles.

3°. That the particles when polarized are in a forced state, and tend to return to their normal or natural condition.

4°. That being, as wholes, conductors, they can readily be charged either *bodily* or *polarly*.

5°. That particles which, being contiguous, are also in the line of inductive action, can communicate or transfer their polar forces to one another *more* or *less* readily.

6°. That those doing so less readily require the polar forces to be raised to a higher degree before this transference or communication takes place.

7°. That the *ready* communication of forces between contiguous

particles constitutes *conduction*, and the *difficult* communication *insulation;* conductors and insulators being bodies whose particles naturally possess the property of communicating their respective forces, easily or with difficulty; having these differences just as they have differences of any other natural property.

8°. That ordinary induction is the effect resulting from the action of matter charged with excited or free Electricity, upon insulating matter, tending to produce in it an equal amount of the contrary state.

9°. That it can do this only by polarizing the particles contiguous to it, which perform this office to the next, and these again to those beyond; and that thus the action is propagated from the excited body to the next conducting mass, and these render the contrary force evident, in consequence of the effect of communication which supervenes in the conducting mass, upon the polarization of the particles of that body.

10°. That therefore induction can only take place through or across insulators: that induction is insulation, it being the necessary consequence of the state of the particles, and the mode in which the influence of electrical forces is transferred or transmitted through or across each insulating medium.

CHAPTER V.

The Leyden phial and battery—Laws of accumulated Electricity—Specific inductive capacity—Lateral discharge—Physiological and chemical effects of frictional Electricity.

(141) *Accumulation of Electricity.—The Leyden Phial.*—In a previous chapter (89) it has been shown that a higher charge may be communicated to the gold leaf Electroscope while under the influence of a second plate *not insulated.* To illustrate this property of the second plate we have only to bring it as close as possible, without touching, to the *inductric* plate, and communicate a charge to the latter; then, on removing the second plate, the accumulation which has been effected will be indicated by an expansion of the gold leaves considerably beyond the original amount. This divergence of the gold leaves is to be considered as occasioned by the attraction in opposite directions of the oppositely electrified inducteous bodies.

(142) When an excited glass tube is brought near to the cap of the Electroscope, the second plate (connected with the earth) being close to it, the gold leaves do not open nearly so much as if the second plate were not there, because induction taking place through the intervening plate of air to the nearest body, viz. the inducteous or second plate, the Electricity of the same kind as that of the cap of the instrument, becomes diffused over the earth (89); but when the second plate is removed, the leaves diverge much more than if it had not been there, because they have received a higher charge. Now, in this case, the intervening air has received a *higher polar tension*, which it will be understood, arises entirely from the close proximity of the charged body to a conductor to the earth: the thinner the intervening stratum of air, the higher the degree of polar tension that can be attained, and the rise of force is limited by the *mobility of the particles of the air*, in consequence of which the equilibrium is restored either silently or by a spark.

(143) If, instead of a plate or stratum of air, we employ a *solid dielectric*, such as glass, the tension which may be assumed is limited only by its cohesive force. Thus, if we place a plate of glass between two circular pieces of tin, insulated, and connect one plate with the prime conductor of an electrical machine, we shall have an

arrangement precisely similar to the condenser (Fig. 33), except that the intervening dielectric will be glass instead of air: on connecting the other plate with the earth to destroy its polar state, and working the machine, the particles of the glass will become powerfully polarized; and if, instead of connecting one of the plates with the earth, we touch it from time to time with the knuckle, a series of sparks will be obtained, occasioned by the repulsion of the positive Electricity naturally present in the tin plate, by induction through the glass from the opposite plate electrified by the machine. After a time these will cease, and on removing the wire connecting the plate with the prime conductor, it will be charged with *positive*, while the other plate will be charged with *negative* Electricity, both in a high state of tension. If now both plates are connected by means of a curved wire, *discharge* results, attended with a vivid flash and a loud snap.

(144) The same effects will be produced by coating either side of a pane of glass with tin-foil, leaving about 1½ inch all round uncovered, and it is quite clear that the surfaces of dielectrics and conductors may be arranged in different forms without impairing the effects. Glass jars or bottles are found much more convenient in practice than squares of coated glass; and the *quantity* of Electricity which may be accumulated depends upon the extent of the coated surface; its *intensity* on the thinness of the glass.

(145) It may be as well here to state the meaning we attach to the words *tension* and *intensity;* terms in constant use, but respecting which some confusion appears to exist in the writings of many electricians. We are disposed to adopt the views of Harris *(Phil. Trans.*, 1834), according to which, *intensity* in common Electricity should be limited to the indications of an Electrometer employed to determine by certain known laws of its relations to an accumulated charge,—the quantity accumulated, or any other electrical element required to be known. Thus, by the use of certain instruments, it is found that with a quadruple attractive force there is *twice* the quantity of Electricity accumulated (60), and so on, the surface remaining the same; again, with a double extent of surface, the same quantity is accumulated as before, when only one-fourth the force is indicated by the Electrometer.* The relations of the indications of the quadrant Electrometer, or of any other Electrometer, to the quantity accumulated, &c. &c., Harris considers as coming under the term *intensity;* for they show, at the same time,

* See Harris's papers in the Transactions of the Royal Society for 1836, Part 2; and for 1839, Part 2.

the force of the charge upon surrounding bodies. *Tension*, Harris applies to *the actual force of a charge* to break down any non-conducting or dielectric medium between two terminating electrified planes. For example, take a coated pane of glass, and charge it in the usual way; then the absolute force exerted by the charge in the intervening glass—the force exerted by the polarized particles of the glass to get out of their constrained state, may be expressed by the term *tension;* and there would be no contradiction or superfluity of terms to talk of the *intensity of the tension* in this sense.

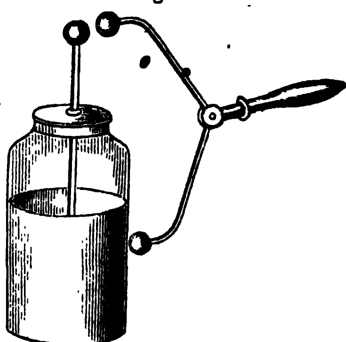
(146) The sum of the matter appears to be this:—*tension* applies to the particles of the electric agency itself,—to a force, in short, such as Faraday has shown to exist in the polarized state of particles of matter, to unfetter themselves, as it were; whereas *intensity* applies to the attractive forces between the terminating plates which are the boundaries of the system, as when a plane, counterpoised at the end of a beam, is caused to descend upon another plane beneath it, by electrical attraction, the weight in the scale pan requisite to balance this force is the intensity between the planes; whereas the *tension* of the charge between them refers to the polarized particles of the dielectric medium,—that is, to the force, whatever it be, by which they endeavour to return to their primitive state. Now, the attraction between the planes may be conceived to be the result of the induction sustained by the particles of the dielectric between them, the force of which may be called *intensity;* and this may differ from the re-active force in the polarized particles themselves,—that is, the force they exert to return to their primitive state. It may be also that this last force is in proportion to the quantity of disturbance in the particles, or in proportion to the quantity of Electricity developed in the terminating planes or coatings; whilst the intensity, or force of attraction between the coatings, supposing them free to move, might be as the square of the quantity of Electricity.

(147) It is very justly observed by Harris, that it would be almost as well perhaps if the term *tension* were banished from common Electricity altogether, as being too hypothetical a word for our present knowledge of Electricity, inasmuch as it is essentially applicable to some species of elastic force. Now, we do not know whether Electricity be a force of this kind or not. The term *intensity* is not open to this objection, because it simply expresses the energy or degree of power with which a particular force operates, be that force what it may.

(148) Glass jars, coated on each side with tin-foil, are well known by the name of Leyden phials, from their having been first con-

structed by Muschenbroek and his friends at Leyden (8). In practice it is found impossible to diminish the thickness of the glass beyond a certain extent, as the constrained position of its polarized particles is apt to rise so high as to destroy its cohesive force, and the charge breaks its way through the glass. Fig. 66 represents a Leyden phial of the usual construction, with the discharging rod furnished with a glass handle in the position in which it is placed, in the act of discharging the jar by establishing a metallic communication between the outer and inner metallic coatings. The wire which passes through the varnished mahogany cover of the jar, is terminated at one end by a brass ball, and at the other by a chain reaching to the bottom of the jar.

Fig. 66.



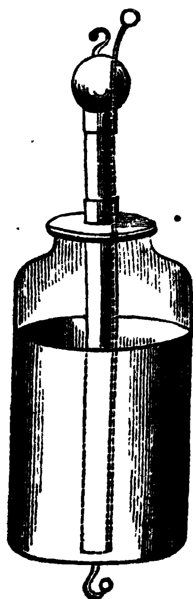
(149) To charge the Leyden phial, its knob should be held about half an inch from the prime conductor, the hand grasping the outer coating. A series of sparks take place between the knob and the conductor, which continue for some time and then cease. The jar is now *charged*, its inside containing positive, and its outside negative Electricity, their union being prevented by the interposed glass. If the jar be very thin, and the tension of the Electricity considerable, discharge frequently takes place through the glass, which thus becomes perforated and useless; or, if the metallic coatings extend too near the mouth of the jar, the discharge is very apt to pass over the uncoated surface in the form of a bluish lambent brush of flame, constituting a spontaneous discharge. But if neither of these accidents occur, still the jar as thus constructed cannot be kept charged long, neutralization taking place more or less rapidly by the conducting substances present in the surrounding atmosphere. It is advisable to varnish the glass above the coating with a solution of gum lac in alcohol, or with the common spirit varnish of the shops, taking care to warm the jars before and after its application.

(150.) In Fig. 66 the Leyden phial is represented as undergoing discharge by an instrument for the purpose; it is not, however, advisable to discharge large phials by placing one of the balls of the discharging rod against its side in this manner, there being some risk of breaking them by the explosion, especially if the glass be thin. The best plan is to place the phial upon a sheet of tin-foil considerably larger than the bottom of the jar, to place the lower

ball of the discharging rod upon the metal, and then to bring the other ball quickly within the striking distance of the knob of the jar; by this method the Electricity becomes diffused over a larger surface, and is not concentrated to a single point of the glass, the risk of fracture of which is necessarily diminished in consequence.

(151) When narrow-mouthed jars or bottles, as the common sixteen ounce phials of white glass (which from their thinness form excellent electric jars), are used, some persons coat them internally with brass filings instead of tin-foil, on account of the difficulty of applying the latter to their interior; for this purpose some thin glue should be poured into them, and the bottle turned slowly round until its inner surface is covered to about three inches from the mouth. Brass filings are then put in, and the bottle well shaken, so that they may be diffused equally over its surface; on inverting it, those which are in excess will fall out, and the bottle will be left tolerably well coated internally. This method, however, rarely answers well; a better one is, to melt equal parts of lead and tin, and whilst fused, to add quicksilver enough to keep the whole fluid whilst warm, and in this condition to pour it into the bottle, turning the latter round and round in various ways till the whole of the inside is covered with amalgam. A little bismuth keeps the whole fluid at a lower temperature. This plan answers very well for coating internally large green glass carboys, though no experimentalist is advised to go to the trouble of fitting up these vessels, as they generally prove useless, probably on account of the imperfection of the dielectric.

Fig. 67.

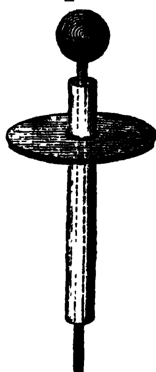


(152) By the construction shown in Fig. 67 the influence of external causes in dissipating the charge of a Leyden jar may to a considerable extent be prevented. The jar is coated with tin-foil as usual, but a glass tube lined internally to rather more than half its length from the bottom, and surmounted with a brass cap, is cemented firmly into the wooden cover. A communication is established between the brass cap and the internal coating by a small brass wire passing loosely through it, and terminating in a small knob. This wire touches the inside of the glass tube. The jar is charged in the usual manner: the wire may then be removed by inverting the jar; the internal coat-

ing is thus cut off from contact with the external air, and the dissipation of the charge prevented. Jars thus arranged have been known to retain their charge for days, and even for weeks.

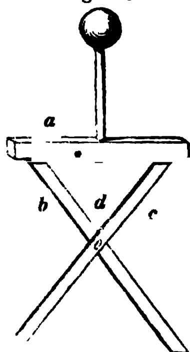
In Fig. 68 a good method of fitting up the Leyden phial is shown: the wire communicating with the interior coating passes through a glass tube extending above and below the cover about six inches. The cover is thus insulated from the inside coating, dust is excluded, and a greater stability is given to the wire. Thus arranged, the jar will retain its charge much longer than on the usual plan. It was contrived by Mr. Barker.

Fig. 68.



(153) The arrangement of the Rev. F. Lockey, by which the fracture of large jars is almost with certainty prevented, is shown in Fig. 69. The wire, instead of communicating with the interior coating by means of a metallic chain, screws into the bar of wood *a*, which is covered with tin-foil, the sides of which press lightly against the inner coating of the jar; two slender pieces of wood, *b*, *c*, also covered with tin-foil, are morticed into the bar *a*, and kept in place by a brass pin at *d*; the other extremities press against the sides of the jar close to the bottom: wide-mouthed jars should be employed, and if they slope towards the bottom, the firmer can the bar *a* be fixed: no covers are required. The advantage of this arrangement will be immediately perceived; there being a metallic communication between the knob and four different points of the inner coating, the force of the discharge is divided into four parts, and not only is the risk of fracture decreased thereby, but a complete discharge of the jar is ensured.

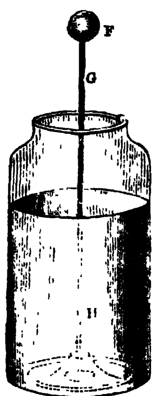
Fig. 69.



A curious fact connected with the fracture of jars, first noticed by Priestley (*History*, p. 611), and afterwards confirmed by Bachhoffner (*Elect. Mag.*, vol. i. p. 282), is, that though a ready passage for restoring the electrical equilibrium is opened by the bursting of the jar, the transmission of the charge takes place through the appropriated circuit without any apparent loss of power. Bachhoffner refers the occasional bursting of jars to an unequal arrangement of particles in certain parts of the glass, whereby the assumption of the polarized state is impeded, so that at these parts more or less time may be requisite to effect an equal degree of polarized intensity

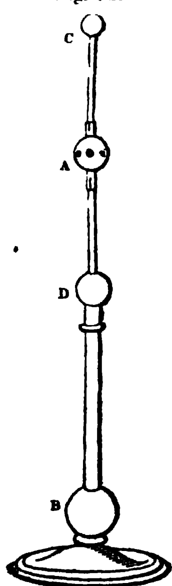
corresponding to the other portions of the jar, and in like manner during discharge more or less time would be necessary to effect their restoration to the natural state.

Fig. 70.



(154) Sir William Harris fits up his jars as seen in Fig. 70. The mouths are open, and the charge is conveyed to the bottom of the jar by a copper tube, G H, three-eighths of an inch in diameter. This tube terminates in a ball, F, of baked wood, and is kept in its place by a convenient foot firmly cemented to the bottom of the jar, which is previously covered with a circle of pasted paper leaving a central portion of the coating free, for the perfect contact of the charging rod, G H, which passes through the centre of the foot as shown by the dotted lines in the figure. When the jars are either employed singly, or are united so as to form a battery (77), they should be placed on a conducting base supported by short columns of glass, or some other insulating substance, so that the whole can be insulated if necessary.

Fig. 71.



In order to allow the jars to be charged and discharged with precision, Harris connects them with what he calls two centres of action, A and B, Fig. 71. The first of these, A, consists of a brass ball which slides with friction on a metallic rod, A D, so as to admit of its being placed at any required height. This ball has a number of holes perforated in its circumference to receive the point of the rod or rods which connect it with the jar or jars. The rod, A B, which supports this ball, may be either insulated on a separate foot, and connected with the prime conductor, or it may be inserted directly into it. The second centre of action consists of a larger ball of metal, B, attached to a firm foot, and placed on the same conducting base with the jar so as to be perfectly connected with it. When the first centre of action, A, requires to have a separate insulation, the insulating glass rod is screwed immediately into the lower ball, B, and sustains the metallic rod above described by the intervention of a ball of baked wood, D, the opposite end of the rod terminating in a similar ball, C, through the

substance of which the conducting communication with the machine passes when it is placed on a separate foot. All the metallic connections should be covered with sealing-wax except at the points of junction, and the wooden balls and different insulations should be carefully varnished. (*Encycl. Brit.*, *art. Electricity.*)

(155) The discharge of the jar is the passage of the electrical forces in their primary state of activity, from a state of tension, into their secondary condition, known as the electrical current. The velocity with which this is effected is so enormous, that it may be regarded as momentary. Nevertheless, the rate at which the forces travel has been measured by Professor Wheatstone, and shown to exceed that of light itself. (*Phil. Trans.* 1834.)

Light is about eight minutes thirteen seconds in passing from the sun to the earth, so that it may be considered as moving at the rate of one hundred and ninety-two thousand miles in a second, performing the tour of the world in about the same time that it requires to wink with our eye-lids, and in much less than a swift runner occupies in taking a single stride.

The sun is ninety-five millions of miles from the earth, and almost a million times larger: the sun being 882,000 miles in diameter, and the earth 8,400 miles. Yet its magnitude, as viewed from the earth, scarcely exceeds that of the moon, which is not more than one-fourth the diameter of our globe, being 2,160 miles in diameter. Such, however, is the velocity of light, that a flash of it from the sun would be seen in little more than eight minutes after its emission: whereas the sound evolved at the same time (supposing a medium like air capable of conveying sound between the sun and the earth), would not reach us in less than fourteen years and thirty-seven days, and a cannon ball, proceeding with its greatest speed, in not less than twenty years.

(156) The velocity of Electricity is so great, that the most rapid motion that can be produced by art appears to be actual rest when compared with it. A wheel, revolving with a rapidity sufficient to render its spokes invisible, when illuminated by a flash of Electricity, is seen for an instant with all its spokes distinct, as if it were in a state of absolute repose; because, however rapid the rotation may be, the light has come and already ceased before the wheel has had time to turn through a sensible space; insects on the wing appear fixed in the air; vibrating strings are seen at rest in their deflected positions; and a rapid succession of drops of water, appearing to the eye a continuous stream, is seen to be what it really is. The following experiment was made by Wheatstone:—A circular piece of pasteboard was divided into three sections, one of which was painted

blue, another yellow, and a third red; on causing the disc to revolve rapidly it appeared white, because a sun-beam consists of a mixture of these colours, and the rapidity of the motion caused the distinction of colours to be lost to the eye: but the instant the pasteboard was illuminated by the electric spark, it seemed to stand still, and each colour was as distinct as if the disc were at rest.

By a beautiful application of this principle, Wheatstone contrived an apparatus by which he has demonstrated that the light of the electric discharge does not last the millionth part of a second of time. His plan was to view the image of a spark reflected from a plane mirror, which, by means of a train of wheels, was kept in rapid rotation on a horizontal axis. The number of revolutions performed by the mirror was ascertained by means of the sound of a siren connected with it, and still more successfully by that of an arm striking against a card, to be 800 in a second, during which time the image of a stationary point would describe 1,600 circles; and the elongation of the spark through half a degree, a quantity obviously visible, and equal to one inch, seen at the distance of ten feet, would indicate that it exists 1,152,000th part of a second. A jar was discharged through a copper wire half a mile in length, interrupted both in the middle and also at its two extremities, so as to give three distinct sparks. The deviation of half a degree between the two extreme sparks would indicate a velocity of 576,000 miles in a second. This estimated velocity is on the supposition that the Electricity passes from one end of the wire to the other; if however the *two* fluids in one theory, or the disturbance of equilibrium in the other, travel simultaneously from the two ends of the wire, the two external sparks will keep their relative positions, the middle one alone being deflected; and the velocity measured will be only one-half that in the former case, viz. 288,000 miles in a second.

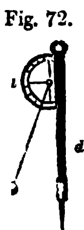
(157) The following were the results actually obtained. In all cases, when the velocity of the mirror exceeded a certain limit, the three sparks were elongated into three parallel lines, and the lengths became greater as the velocity of the mirror was increased. The greatest elongation observed was about 24°, indicating a duration of about the 24,000th part of a second. The lines did not always commence at the same places: sometimes they appeared immediately below the eye, sometimes to the right, at other times to the left, and occasionally they were out of view altogether. This indetermination was owing to the arm not always taking the spark at the same distance from the discharger, several discharges were therefore required to be made before the eye could distinctly observe the appearances. When the velocity was low, the terminating points

appeared to be exactly in the same vertical line, but when the velocity was considerable and the mirror revolved towards the *right*, the lines assumed this appearance: ——— when it revolved towards the left, they appeared thus: ——— in no case were they seen thus: ——— or thus: ——— as required by the hypothesis of a single fluid.

The spark board was 10 feet from the mirror, and the duration between the extreme sparks and the middle one could not have exceeded one-half of a degree. The general conclusions drawn from the experiments were: 1st. That the velocity of Electricity through a copper wire exceeds that of light through the planetary space. 2nd. That the disturbance of the electric equilibrium in a wire communicating at its extremities with the two coatings of a charged jar, travels with equal velocity from the two ends of the wire, and occurs latest in the middle of the circuit. 3rd. That the light of Electricity in a state of high tension has less duration than the millionth part of a second; and 4th. That the eye is capable of perceiving objects distinctly, which are presented to it during the same interval of time.

(158) The quantity of Electricity accumulated in a jar or battery may be roughly estimated by the number of turns of the machine, or more correctly by the unit jar (Fig. 96); its intensity may be approximately determined by the amount of repulsion between any two moveable bodies under its influence, or rather by the amount of their opposite attractions by surrounding bodies under their inductive influence.

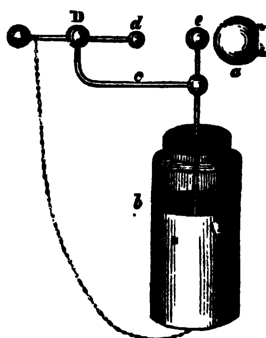
Fig. 72.



In Fig. 72 is shown the quadrant electrometer, invented by Henley for this purpose. It consists of a graduated semicircle of ivory fixed to a rod of wood *d*. From the centre of *a* descends a light index, terminating in a pith-ball, and readily moveable on a pin. To use it, it is removed from its stand and screwed upon the jar or battery, the charge of which it is intended to indicate: as it increases, the pith-ball moves from its centre of suspension, and measures the intensity upon the graduated semicircle.

(159) When a series of explosions from a Leyden phial is required for any particular purpose, it is useful to have a contrivance by which the discharges can be effected without the interference of the operator. Fig. 73 represents the apparatus of Mr. Lane for this purpose. *a* is the prime conductor of an electrical machine; *b* the jar, on the wire communicating with the interior of which is fixed the arm of varnished glass *c*, on the end of this is cemented the brass knob D; through this ball the wire *f d* slides, so that the ball

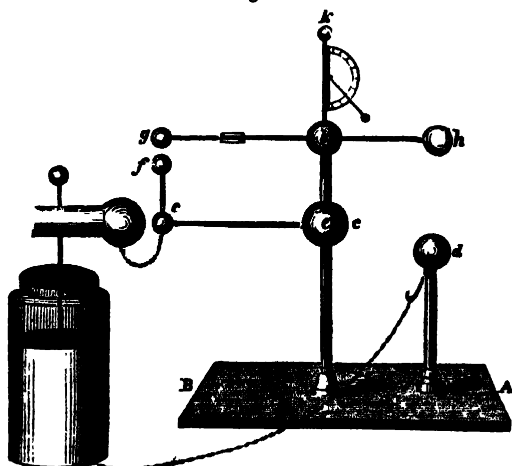
Fig. 73.



d may be brought to any required distance from the knob of the jar *a*. A simple inspection of the figure will show how this discharging electrometer acts, and how, by increasing or lessening the distance between *d* and *e*, the strength of the charge may be regulated.

(160) Another useful instrument is the balance electrometer of Cuthbertson, shown in Fig. 74. A B is a wooden stand, about eighteen inches long and six broad, in which are fixed two glass supports *d e*, mounted with brass balls; under the ball *d* is a brass hook: the ball *b* is made of two hemispheres, the under one being fixed to the brass mounting, and the upper one turned with a groove to shut upon it, so that it can be taken off at pleasure: it is screwed to a brass tube about four inches long, fitted on to the top of *e*; from its lower end proceeds an arm carrying the piece *f c*, being two hollow balls and a tube, which together makes nearly the same length as that fitted on to *e*: *g h*, is a straight brass wire, with a knife-edged centre in the middle, placed a little below the centre of gravity, and equally balanced with a hollow brass ball at each end, the centre or axis resting upon a proper shaped piece of brass fixed in the inside of the ball *b*; that part of the hemisphere towards *h* is cut open to

Fig. 74.

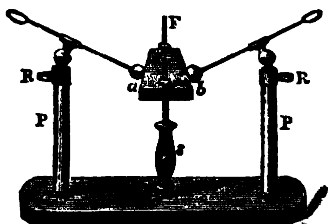


permit that end of the balance to descend till it touches *d*, and the upper hemisphere *b* is also cut open: the arm *g* is divided into sixty grains, and furnished with a slider, to be set at the number of grains

the experiment requires: *k* is a common Henley's Electrometer screwed upon the top of *b*. The slider is placed loosely on the arm *g*, so that as soon as *g h* is out of the horizontal position it slides forward towards *f*, and the ascending continues with an accelerated motion till *h* strikes *d*.

Now suppose the instrument to be applied to a jar as in the figure; a metallic communication by a wire or chain is established between *c* and the inside of the jar, *k* is screwed upon *b* with its index pointing towards *h*, the increase of the charge in the jar is thus shown: suppose the slider to be set at fifteen grains, it will cause *g* to rest upon *f* with a pressure equal to that weight: as the charge increases in the jar the balls *f* and *g* become more and more repulsive of each other; and when the force of this repulsion is sufficient to raise fifteen grains, the ball *g* rises, the slider moves towards *b*, and the ball *h*, coming rapidly into contact with *d*, discharges the jar, and as the force of the repulsion depends upon the intensity of the charge, the weight it has to overcome affords a measure of this intensity, and enables the experimenter to regulate the amount.

Fig. 75.

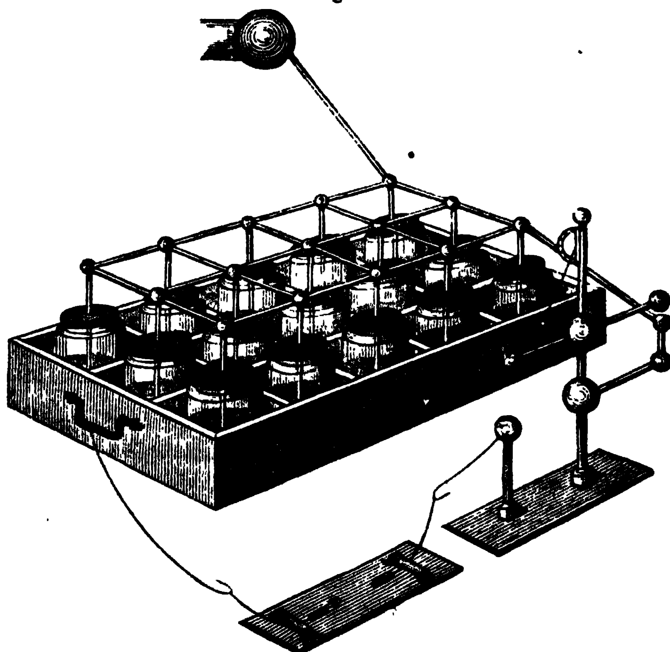


(161) A very useful piece of apparatus for directing with precision the charge of a jar or battery, is Henley's Universal Discharger, Fig. 75; it consists of a wooden stand with a socket fixed in its centre, to which may be occasionally adapted a small table having a piece of ivory (which is a non-conductor) inlaid on its surface. The table may be raised and kept at the proper height by means of a screw *s*. Two glass pillars P P are cemented into the wooden stand. On the top of each of these pillars is fitted a brass cap having a ring R attached to it, containing a joint moving both vertically and horizontally, and carrying on its upper part a spring tube admitting a brass rod to slide through it. Each of these rods is terminated at one end either by a ball *a b* screwed on a point, or by a pair of brass forceps, and is furnished at the other extremity with a ring or handle of solid glass. The body through which the charge is intended to be sent, is placed on the table, and the sliding rods, which are moveable in every direction, are then by means of the handles brought in contact with the opposite sides, and one of the brass caps being connected with the outside of the jar or battery, the other may be brought into communication with the inner coatings by means of the common discharging rod, Fig. 67. For some experiments it is more convenient to fix the substance on

which the experiment is to be made in a mahogany frame F, consisting of two small boards which can be pressed together by screws, and which may then be substituted for the table. In either of these ways the charge can be directed through any part of the substance, with the greatest accuracy.

(162) When several jars are electrically united together, the arrangement is called an Electrical Battery. Fig. 76 represents such an apparatus. It consists of fifteen jars, the inside coatings of all of which are metallically connected by brass rods, and the bottom of the box in which they stand, being lined with tin-foil, secures a continuous conducting surface for the exterior coatings. The battery is shown with a Cuthbertson's Balance Electrometer, and an apparatus for striking metallic oxides attached. It is charged in the same

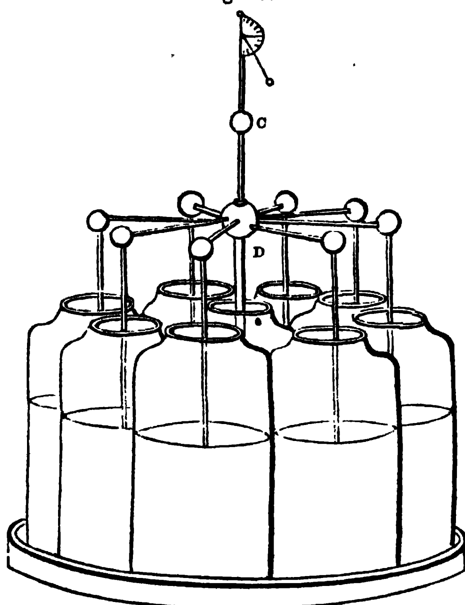
Fig 76.



manner as a single jar, by connecting the metallic rods in communication with the inside coatings with the prime conductor, as shown in the figure; the metallic lining of the box being in good conducting communication either with the negative conductor or with a good discharging train. This does not seem, however, to be the best method of arranging a battery. The jars, according to Harris's experience, should be disposed round a common centre (Fig. 77), that centre being in communication with the prime conductor. As

shown in the figure, the central insulated rod C D is in direct communication with the prime conductor, the remaining jars being connected with each other. Harris found the difference between the two modes of arrangement to be considerable, and in a battery of five jars, each containing five square feet of coated surface, to amount to one fifth of the entire accumulation.

Fig. 77.



(163) By thus multiplying the number of jars we have it in our power to accumulate Electricity to an extent limited only by the charging power employed. A prodigious apparatus was constructed towards the end of the last century by Cuthbertson for the Tylerian Society at Haerlem. It consisted of one hundred jars of five and a half square feet each, so that the total amount of coated surface was five hundred and fifty square feet. This battery, when charged with Van Marum's large machine (102), produced the most astonishing effects. It magnetized large steel bars, rent in pieces blocks of box-wood four inches square; melted into red hot globules iron wires 25 feet in length and $\frac{1}{150}$th of an inch in diameter, and dissipated in a cloud of blue smoke tin wires 8 inches long and $\frac{1}{16}$th of an inch in diameter. The management of large electrical batteries demands considerable caution, as the discharge of a far smaller extent of coated surface than that just described, through the body of the operator, would be attended with serious conse-

quences: by employing, however, the balance electrometer of Cuthbertson (Fig. 74), or the simple apparatus invented by Harris, and shown in Fig. 95, p. 137, all danger may be avoided.

(164) The extent of charge which a jar or battery is capable of receiving may be considerably augmented by moistening the interior. It was noticed by Mr. Brooke (*Cuthbertson's Electricity*, p. 169) that a coated jar would take a higher charge when dirty than when clean, and in 1792 Cuthbertson made the casual discovery that a fresh coated jar, the inside of which was a little damp, would take a higher charge than it could do after it had been coated for some time and was quite dry. This observation induced him to make a series of experiments. He found that a battery composed of fifteen jars, and containing seventeen square feet of coated glass which on a very dry day in March (1796) could only be made to ignite *eighteen* inches of iron wire, took a charge which ignited *sixty* inches when he breathed into each jar through a glass tube. He first thought he had thus obtained a method of making one battery perform the functions of three, but his subsequent experiments on the fusion of wires by various quantities of Electricity at the same intensity, led him to the conclusion that the increase of effect was equivalent to the addition of *six jars*. A jar containing 168 square inches of coating, made very dry, and arranged with his balance electrometer and eight inches of watch pendulum wire, included in the circuit in the manner shown in Fig. 76, was found to discharge spontaneously without affecting the separation of the balls *g f*, when the slider was set at *thirty;* but when the inside of the jar was moistened by breathing into it no spontaneous explosion occurred, but the discharge took place through the electrometer, and the wire was fused into balls.

(165) The tendency of jars to spontaneous explosion when very clean and dry, may be diminished without moistening their insides, by pasting a slip of writing paper, about an inch broad, on the inner surface of the jar, so as to cover the uncoated interval to the height of half an inch above the upper edge of the inner coating. The action of this and of the other means that have been employed for the same purpose, consists, according to Singer (*Elements of Electricity*, p. 135), in a gradual diminution of the intensity of the charge at that part from which it has the greatest tendency to explode, by an extension of the charged surface through the medium of an imperfect conductor. The height of the uncoated rim of small jars should, according to the same authority, be about two or two and a half inches; with larger jars a rim of three inches will be sufficient if they are fitted up with an interior paper band. Singer also recommends to interpose a thickness of writing paper between the coating and the glass, which may easily be effected by pasting

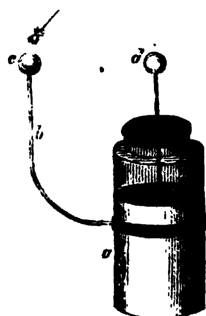
the tin-foil first on paper, and afterwards applying this combined coating to the glass. The metallic coatings are thus placed at a greater distance from each other, and the chance of fracture is diminished. But jars thus fitted up, though they admit of a much greater quantity of Electricity being disposed on them than other jars without paper, have not for equal quantities of Electricity the same amount of action, the intensity of the Electricity being much less. A thin jar will, with the same amount of attractive force, ignite more wire than a thick one.

(166) A few experiments illustrative of various phenomena connected with the charge and discharge of coated glass may here be introduced.

Experiments with the Leyden phial and battery.

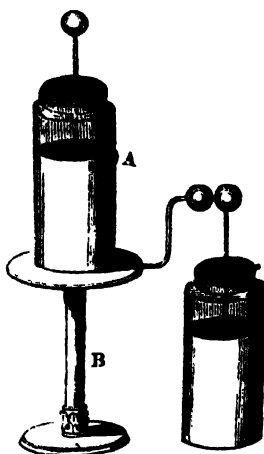
Ex. 1. Fix to the outside coating of the jar, *a*, Fig. 78, exposing about a square foot of coated surface, a curved wire *b*, terminated by a metallic ball *c*, rising to the same height as the knob of the jar *d*; charge the jar, and suspend midway between *c* and *d*, by a silken thread, a small ball of cork or elder pith. The ball will immediately be attracted by *d*, then repelled to *c*, again attracted, and again repelled, and this will continue for a considerable time: when the motion has ceased, apply the discharging rod to the jar, no spark or snap will result, proving that the phial has been gradually discharged by the pith or cork ball, the motion of which from *d* to *c* likewise proving the opposite electrical states of the outer and inner coatings

Fig. 78.



Ex. 2. Place the jar A, Fig. 79, on the insulating stand B, and attempt to charge it from the prime conductor, you will find it impossible; now apply the knuckle to the outside coating, and continue to turn the machine: for every spark that enters the jar, one will pass between the outside coating and the knuckle, and on applying the discharging rod, the jar will be found to have received a charge. Instead of the knuckle, the knob of a second *uninsulated* jar C, may be applied as in Fig. 79, *both* jars will receive a charge.

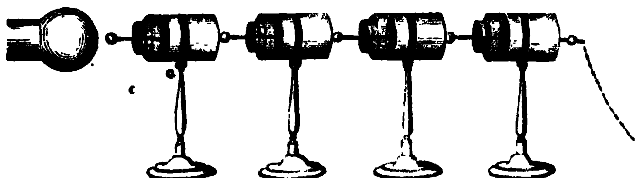
Fig. 79.



This experiment was made by Franklin in confirmation of his theory that when a jar is charged it contains in reality no

more Electricity than it did before, and that during the act of charging the same quantity of "*fire*" was thrown out of one side of the glass as was thrown on the other side from the conductor of the machine. In order to demonstrate this still more conclusively he arranged a series of jars, as shown in Fig. 80, taking care to

Fig. 80.



establish a good connection between the outside of the last jar and the earth, and he found that "the fluid that was driven out by the first would be received by the second, and what was driven out of the second would be received by the third, &c. A great number of jars could therefore be charged with the same labour as one, but not equally high, as every bottle in the series receives the new fire and loses its old with some reluctance, or rather gives some small resistance to the charging, and this circumstance in a number of bottles becomes more equal to the charging power, and so repels the fire back again on the globe sooner than a single bottle will do." (*Franklin's Letters*, p. 12.) This method of charging a series of jars, by giving a direct charge to the first only, is called charging by *cascade*. The jars may be separated and discharged singly, or they may be so connected as to produce *one* discharge the force of which shall be equal to the sum of all the separate ones. For this purpose they are placed upright on one common conducting basis, and their interior coatings connected metallically together: the whole series may then be discharged precisely in the same manner as a single jar. In fact, the arrangement then becomes an ordinary electrical battery. Mr. I. Baggs, in a communication to the Royal Society (Jan. 13th, 1848), describes a method of charging and placing jars by which a disruptive spark (124) of unusual length and brilliancy is easily produced. The jars are charged separately and to the same degree of intensity, then quickly placed in series of positive and negative surfaces, very near, but not so as to touch.

Ex. 3. The following experiment furnishes another beautiful illustration of the theory of the Leyden jar. It is called the *luminous* or *diamond* jar. The figure represents a jar the coatings of which are made up of fifty-five squares of tin-foil 1 inch square, and each perforated with a hole $\frac{1}{10}$ths of an inch in diameter, and pasted in five

rows inside and outside of the jar. The diagonals of the square pieces are placed horizontal and vertical, and their points or angles are separated by about $\frac{1}{12}$th of an inch. The rows of the tin-foil squares are similarly placed on the inside of the jar, except that their horizontal points nearly touch one another at the centres of the circular holes of the outer squares. During the charging of the jar the sparks are seen jumping from one metallic surface to the other; and when the jar is discharged every part of the jar within the boundaries of the metallic spangles becomes momentarily illuminated, and presenting in a darkened room an exceedingly brilliant appearance.

Fig. 81.



Ex. 4. Provide a jar the exterior coating of which is moveable (it may be made of thin tin plate); charge this jar in the usual manner, and then place it on an insulating stand: touch the knob from time to time with a conducting body; the whole charge will thus ultimately be removed, and the glass will be brought to its natural state: now charge the jar again, remove the outer coating, and re-place it on the insulating stand; in this state it will retain its charge for an indefinite period. The reason of this is, that the wire by which the charge is communicated to the interior coating, being left attached to it, induction does not take place solely through the glass to the opposite coating, but is partly directed, through the air, to surrounding conductors: this portion is usually called *free charge*, and on removing this, by touching the knob with a conducting body, a corresponding portion of free charge, of the opposite kind, makes its appearance on the outside coating, owing to the induction which is now at liberty to direct itself from that part to surrounding objects. But when the exterior coating is removed the induction is determined entirely *through the glass*, and the charge on one side is sustained by an exactly equal quantity of the contrary Electricity on the other: all interference with surrounding objects is thus cut off.

Ex. 5. Provide a jar with both coatings moveable (the jar for this purpose must be as wide at the mouth as at the bottom): let the wire communicating with the interior coating pass through a glass tube, by which it may be removed from the jar without touching the metal: charge the jar in the usual manner, then withdraw the inside coating; and having set it aside invert the jar upon some badly con-

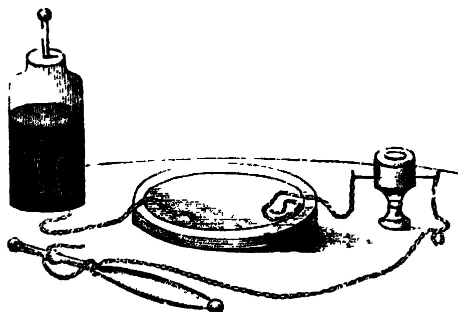
ducting body, such as the table-cloth, and remove the exterior coating; then, on applying the discharging rod to the two coatings, no spark or explosion will take place, and they may be taken in the hands without producing any shock, proving them to be quite free from any electrical charge: now re-place the coatings on the jar, and complete the circuit with the discharging rod: both spark and explosion will result, proving that the charge of the Leyden jar is dependent on the dielectric glass, and that the only use of the coatings is to furnish a ready means of communication between the charged particles.

Ex. 6. Place a charged jar on an insulated stand, and make a communication between the interior coating and the electric bells, Fig. 50: they will remain at rest until the outside of the jar is connected with the earth, when the clappers will be set in active motion: thus, by touching the exterior coating from time to time with the finger, the bells may be made to ring at pleasure.

Ex. 7. Place some gunpowder on the ivory slip of the table of the universal discharger, Fig. 75, and having unscrewed the balls *a b*, insert the points of the wires into the powder about half an inch apart: on passing an explosion from the Leyden phial through the powder, it will be scattered in all directions but *not* ignited, an effect occasioned, probably, by the enormous velocity (288,000 miles in a second, according to Wheatstone's experiments) with which Electricity travels, not allowing sufficient time to produce the effects of combustion; that this is the reason is rendered apparent by—

Ex. 8. In which some loose gunpowder is placed in the ivory

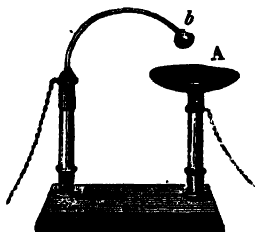
Fig. 82.



mortar, Fig. 82, and the circuit interrupted by ten or twelve inches of water in a porcelain basin: under these circumstances the gunpowder is fired on discharging the jar.

Fig. 83 represents Mr. Sturgeon's apparatus for firing gunpowder. The powder is placed in the wooden cup A, either dry or made up into a pyramidical form with a little water. The brass ball *b*, which moves on a joint, is brought immediately over it, the chains *c d*, being connected with the outer and inner surfaces of a Leyden jar. The discharge takes place, and the powder is inflamed.

Fig. 83.



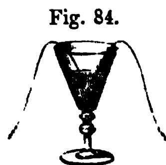
Ex. 9. Tie some tow loosely round one of the knobs of the discharging rod, and dip it in powdered resin: place the naked knob in contact with the outside of a charged jar, and bring the other quickly in contact with the ball *a*: discharge will take place, and the resin will burst into a flame.

Ex. 10. Place a thick card or some leaves of a book against the outer coating of a Leyden jar, or between the knobs of the universal discharger: pass the explosion, the discharge will pass through the paper or card, and perforate it, producing a burr or protrusion in both directions, as though the force producing it had acted from the centre of the thickness of the card outwards; a strong and peculiar odour is at the same time developed.

Ex. 11. Drill two holes in the ends of a piece of wood half an inch long and a quarter of an inch thick: insert two wires in the holes, so that the ends within the wood may be rather less than a quarter of an inch distant from each other: pass a strong charge through the wires, and the wood will split with violence. Stones may be split in a similar manner.

Ex. 12. Hang two curved wires, provided with a knob at each end, in a wine-glass nearly full of water, so that the knobs shall be about half an inch asunder: connect *a*, Fig. 84, with the outer coating of a charged jar, and *b* with the inner coating, by means of the discharging rod; when the explosion takes plass the glass will be broken with great violence.

Fig. 84.

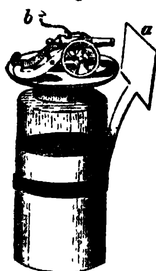


Ex. 13. Remove the press from the universal discharger, and place a lighted candle in the socket: unscrew the balls, and arrange the points of the wires a little above the top of the wick of the candle, and about one inch apart: charge a jar, and having blown out the candle, make the connections between the outer and inner coating: the jar will discharge itself through the smoke of the candle, and re-light it.

Ex. 14. Adjust the candle so that the flame shall be exactly on a level with the two points of the discharging wires: set the point of the wire which is to communicate with the interior coating of the jar at the distance of one inch and a half from the flame, snuff the wick of the candle very low, and complete the circuit: the jar will discharge itself slowly and put out the candle.

Ex. 15. Remove the candle, and screw the table into the socket of the universal discharger: place a lump of sugar on the ivory slip, and having screwed the brass balls on the discharging wires, bring the surface of the sugar to nearly the same height as the centre of the balls. Fix Lane's discharging electrometer, Fig. 73, on the Leyden phial, and interpose the universal discharger between the chain *f* and the outside coating of the jar: darken the room, and turn the electrical machine. When the jar is charged sufficiently high, it will discharge itself over the surface of the sugar, illuminating it, and the light will continue for some time. If five or six eggs be arranged in a straight line, and in contact with each other, they will be rendered luminous by passing a small charge through them.

Fig. 85.



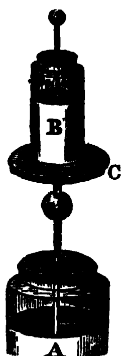
Ex. 16. Place a little model of a brass cannon on a circular brass plate fixed on the top of a Leyden phial instead of the ball, as shown in Fig. 85: connect the square piece of brass *a* with the exterior coating, and arrange it at the distance of about half an inch from the mouth of the cannon: bring the knob *b* of the cannon in contact with the prime conductor, and hold a card between the mouth of the cannon and the brass plate *a*, so that it shall not touch either: when the jar has received a sufficient charge, the explosion will pass, and the card will be perforated, as in experiment 10.

Ex. 17. Colour a card with vermilion, unscrew the balls from the universal discharger, and place the points on opposite sides of the card, one about half an inch above the other; discharge a jar through the card, it will be perforated at the point opposite to the wire connected with the *negative* side of the jar; a zig-zag black line of reduced mercury will be found extending from the point where the positive wire touches the card to the place of perforation. This curious result arises from the great facility with which positive Electricity passes through air, as compared to negative; and on repeating the experiment *in vacuo*, the perforation always takes place at a point *intermediate* between the two wires.

Ex. 18. To the knob of a large jar A, Fig. 86, screw a small

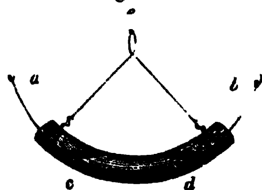
metallic stage C, on which place a small jar B; charge the large jar in the usual manner: the small jar, though it will not be charged in the usual acceptation of the term, will nevertheless be in a state of polarization; and on bringing one ball of the discharging rod in contact with the exterior coating of the large jar, and the other in contact with the knob of the small jar, a flash and report will result, arising from the neutralization of a portion of the negative Electricity of the outside surface of A, by a corresponding portion of positive Electricity from the interior of B: *both jars* will now be charged, the inner surface of A and the outer surface of B being positive, and the outer surface of A and the inner surface of B negative; and both jars may be discharged together, by connecting the inside of B by means of a wire or chain with the outside of A, and bringing one knob of the discharging rod in contact with this wire or chain, and the other on the stage C, on which the small jar stands. If the large jar A be first discharged in the usual manner, by bringing one knob of the discharging rod in contact with its outside coating, and the other within striking distance of the stage C, a second charge will be communicated to it, by the electro-polar influence of the small jar, the moment that the discharging rod is removed; and a second small explosion will take place on applying the discharging rod, after which both jars will be reduced nearly to a state of neutrality.

Fig. 86.



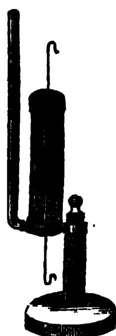
Ex. 19. Fill the bent glass tube, *c d*, Fig. 87, with resin, or sealing-wax, then introduce two wires, *a b*, through its ends, so that they may touch the resin and penetrate a little way into it: let a person hold the tube over a clear fire by the silk string *e*, so as to melt the resin, and at the same time connect the wires with the interior and exterior coatings of a charged jar: while the resin is solid, the discharge cannot take place through it, but as it melts it becomes a conductor, and then the discharge passes freely.

Fig. 87.



Ex. 20. The sudden rarefaction which air undergoes during the passage of the electric spark through it, is well shown by an apparatus invented by Mr. Kinnersley, of Philadelphia, and shown in Fig. 88. It consists of a glass tube ten inches long and two inches in diameter, closed air-tight at both its ends by two brass caps: a small glass tube, open at both ends, the lower one bent at a right angle, passes through the bottom cap, and enters the water contained in the

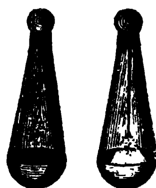
Fig. 88.



lower portion of the large tube. Through the middle of each of the brass caps a wire is introduced, terminating in a brass knob within the tube, and capable of sliding through the caps, so as to be placed at any distance from each other. If the two knobs be brought into contact, and a Leyden jar discharged through the wires, the air within the tube undergoes no change in volume: but if the knobs are placed at some distance from each other when the jar is discharged, a spark passes from one knob to the other: the consequence is a sudden rarefaction of the air in the tube, shown by the water instantaneously rising to the top of the small tube, and then suddenly subsiding; after which it gradually sinks to the bottom of the tube, the air slowly recovering its original volume.

Ex. 21. Fig. 89 represents two small electric jars, coated as usual, *externally*, and provided with valves to withdraw the air from them by means of an air-pump. After the exhaustion, brass balls are screwed on the necks of the jars over the valves. From the brass caps wires proceed a few inches within the phials, terminating in blunt points. A jar fitted up in this manner may be charged and discharged like a common Leyden phial, induction taking place with great facility through highly rarefied air. When charged and discharged in a dark room, the extremity of the wire in the inside becomes beautifully illuminated with a *star* or *pencil* of rays (as shown in the figure), according as the Electricity happens to be positive or negative. This experiment is known as the Leyden vacuum.

Fig. 89.

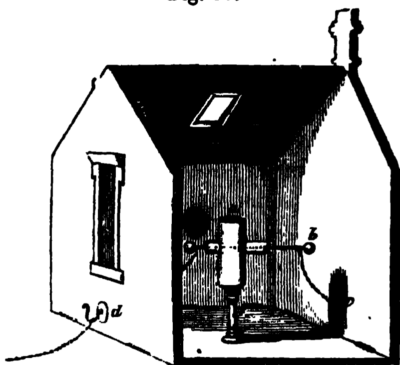


Ex. 22. One of the most beautiful experiments in Electricity is that called (though most improperly) the "falling star:" it is produced by transmitting a considerable electrical accumulation through an exhausted receiver. Singer, in his excellent "Elements of Electricity," recommends a glass tube, five feet in length and $\frac{3}{8}$ of an inch in diameter, capped with brass at each extremity. When such a tube is exhausted, no ordinary Electricity will pass through it in any other than a diffused state; but by employing the charge of a very large jar, *intensely charged*, a brilliant flash is obtained through the whole length of the tube. The metallic termination in the tube should be a very small and well polished ball; and if care be taken to have the brass caps well rounded, and the air within the tube not too much attenuated, the experiment will rarely fail. If the tube be six feet long, it may be four inches in

diameter, and a jar having five square feet of coating should be employed. An assistant should work the pump, and the operator should occasionally try to pass the charge down; when at a certain degree of exhaustion, it does so in a brilliant line of white light.

Ex. 23. Fig. 90 represents an apparatus for showing the explosion of gunpowder by Electricity. It is generally made seven or eight inches long, and nearly the same height to the top of the roof; the side, and that half of the roof next the eye, are omitted in the figure, that the inside may be more conveniently seen. The sides, back, and front of the house are joined to the bottom by hinges; the roof is divided into two parts, which are also fastened by hinges to the sides: the building is kept together by a ridge fixed half way on one side of the roof, so that when the building is put together it holds it in its place. Within the house there is a brass tube 1½ inch long, and ⅝ of an inch in diameter, screwed on to a pedestal of wood, which goes through about one-eighth of an inch, the other end by means of a chain has a communication to the hook *d;* at the other side of the tube, a piece of ivory, one inch long, is screwed, with a small hole for a wire to slide into.

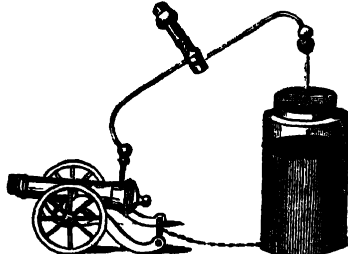
Fig. 90.



To use this apparatus, fill the brass tube *a* with gunpowder, and ram the wire *b* a small way into the ivory tube; then connect the hook *c* with the bottom of a large jar, interposing a dish of water as in Fig. 82: charge the jar, and form a communication from the hook *d* to the knob; discharge will take place, the gunpowder will explode, throwing asunder the roof, upon which the sides, front, and back will fall down, without, however, undergoing any damage. The apparatus may be placed on the ground, or on a table out of doors, communication being established with the Leyden phial within by means of insulated wires.

Ex. 24. Fig. 91 exhibits a piece of apparatus for showing in an amusing manner the power of the electric discharge to cause the elements of water, viz., oxygen and

Fig. 91.



hydrogen, to enter into combination. The metallic wire which passes through the touch-hole of the small brass cannon is insulated from the metal by a hollow tube of ivory: this wire reaches nearly but not quite across the bore of the barrel. The cannon is charged in the following manner:—the mixture of the oxygen and hydrogen gas being ready in a 4 or 6 oz. stoppered bottle, the cannon is filled with sand, and being held close to the mouth of the bottle, the stopper is removed, and the sand from the cannon entering, the gas at the same moment ascending occupies its place. The mouth of the cannon is closed by a cork, which is projected to a considerable distance by the force of the explosion. A single inspection of the figure will show the manner of passing the electric discharge.

Ex. 25. The following experiment is exceedingly beautiful, and highly interesting, as demonstrating the opposite electric states of a charged jar. Make the resinous cake of an electrophorus dry and warm: draw lines on it with the knob of a positively charged jar, and sift over these places a mixture of sulphur and red-lead; on inclining the plate to allow the excess of the powder to fall off, every line marked by the knob of the jar will be observed covered with the *sulphur*, whilst the *minium* will be dispersed. On wiping the plate, and drawing figures with the outside of the jar, the *sulphur* will be dispersed, and the *minium* collected in a very elegant manner on the lines described by the outside of the jar. The rationale of this experiment is as follows:—the sulphur and red-lead, by the friction to which they have been exposed, are brought into opposite electrical states, the sulphur is rendered negative, and the red-lead positive, so that when the mixture is made to fall on surfaces possessing one or the other Electricity in a free state, the sulphur will be collected on the positive, and the minium on the negative portions of the plate, according to the well-known law of electric attraction. This experiment may be varied by tracing various lines at pleasure on a smooth plate of glass, with the knob of a jar, charged first with positive and then with negative Electricity: on gently dusting the surface with the mixture of sulphur and red-lead, a series of red and yellow outlines will be formed. This experiment is known as "Lichtenberg's figures."

The mechanical effects, and calorific phenomena accompanying the discharge of an electric battery, are exemplified in the following experiments.

Ex. 26. Between the boards of the press of the universal discharger (Fig. 75) lay a piece of stout plate-glass, and send a powerful charge through it, the glass will not only be broken into fragments, but a portion even reduced to an impalpable powder.

Ex. 27. Lay a fine iron chain, about two feet long, upon a sheet

of white paper, and transmit a charge from six or eight square feet of coated surface through it: on removing the chain, its outline will be observed marked upon the paper with a deep stain at each link, indeed, if this charge is sufficiently powerful, the paper is frequently burnt through.

Ex. 28. Place a slip of tin-foil, or of gold leaf, between two pieces of paper, allowing the ends to project, and press the whole firmly together between the boards of the press of the universal discharger; transmit the shock of a battery through it, the metals will be completely oxidized; if gold leaf be the metal employed, the paper will be found stained of a deep purple hue.

Ex. 29. If a piece of paper be laid on the table of the discharger, and a powerful shock directed through it, it will be torn in pieces.

The electrical battery is exhibited in Fig. 76, in the arrangement for fusing metallic wires, and converting them into oxides, and in Fig. 74 a large jar is represented in the experiment of fusing fine iron wire, a wire being substituted in place of the chain at *c*. The best material for this purpose is the finest flattened steel, sold at the watchmakers' tool shops, under the name of watch-pendulum wire. It does not require a large extent of coated surface merely to fuse metallic wires, provided they are sufficiently thin; but to effect their oxidation, large batteries are necessary.

Fig. 92.

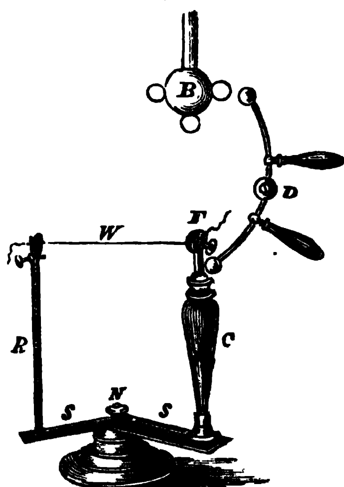


Fig. 92 represents a useful apparatus for deflagrating metallic wires, invented by Professor Hare. Two brass plates *s s*, are fixed in a pedestal by a bolt N, about which they have a circular motion. On one of the plates a glass column C is cemented, surmounted by a forceps F; at the corresponding plate there is a brass rod R, furnished also with a forceps. Between this forceps and that at F the wire through which the electric charge is to be sent is stretched; it may be of various lengths, according to the angle which the plates *s s* make with each other. The bottom of the pedestal is in communication with the exterior coating of a jar or battery which is charged from the prime conductor B, and with which it is allowed to remain in communication. Now, it is obvious that in this case, touching the conductor is equivalent to touching the inner

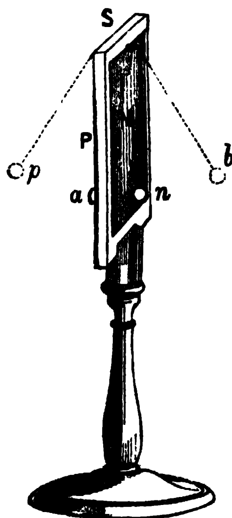
coating of the battery. However, by causing one of the knobs of the discharger D to be in contact with the insulated forceps F, and approximating the other knob to the prime conductor, the charge will pass through the wire W.

The oxides of metals produced by sending powerful electric discharges through fine wires, and which may be preserved by stretching them about $\frac{1}{8}$ of an inch above sheets of white paper, are exceedingly beautiful: the wires disappear with a brilliant flash, and the paper is found marked as described below (from Singer's Electricity), though no description can convey an adequate idea of the beauty of the impressions.

	Diameter.	Colour of the Oxides on paper.
Gold wire	$\frac{1}{180}$ of an inch	purple and brown.
Silver	$\frac{1}{160}$ "	grey, brown, and green.
Platinum	$\frac{1}{180}$ "	grey and light brown.
Copper	$\frac{1}{180}$ "	green, yellow, and brown.
Iron	$\frac{1}{180}$ "	light brown.
Tin	$\frac{1}{180}$ "	yellow and grey.
Zinc	$\frac{1}{180}$ "	dark brown.
Lead	$\frac{1}{180}$ "	brown and blue grey.
Brass	$\frac{1}{180}$ "	purple and brown.

Ex. 30. By the following experiment it will be proved that Electricity exerts an agency directly the reverse of the above, viz., that of restoring to the metallic state oxide of tin. If a portion of this oxide be enclosed in a glass tube, and a succession of strong explosions directed through it, the glass will after a time be found stained with metallic tin; and vermilion may be resolved into mercury and sulphur, by the charge of a moderate sized jar.

Fig. 93.



Ex. 31. The equality of two Electricities disposed on the inner and outer surfaces of the Leyden jar was proved by Franklin's experiment (Ex. 1).

The following beautiful illustration by Richman is likewise full of instruction on this point. Let a plate of coated glass, S, be placed vertically on a stand, and let two pith-ball electroscopes, *p n*, be attached to the coatings. Bring the coating P into contact with the prime conductor, the coating N being in good conducting communica-

tion with the ground. As the charging proceeds the ball *p* will be repelled by the free Electricity of P, while the ball *n* retains its original position. On allowing the apparatus to remain undisturbed for some time, the free Electricity of P will be gradually dissipated, and the ball *p* will drop into its original position. Now charge the plate again, and immediately cut off the communication between N and the ground. The ball *p* will slowly descend towards P as before, but at the same time *n* will begin to rise, and by the time *p* has reached the position *a*, *n* will have risen to *b*, the angle between the balls being about the same as at first. Both balls will then slowly sink till the charge is lost by dissipation. If during the descent of the balls we touch N, the ball *n* will suddenly sink, and *p* will as suddenly rise by an equal amount. On removing the finger from N, *p* will fall and *n* will rise to nearly their former places, and the slow descent of both will again recommence. The same thing will happen if we touch P,—*p* will fall down close to the plate, and *n* will rise, and so on; and these alternate touchings of the coatings may be repeated a great many times before the plate is discharged.

In order to understand this beautiful experiment it must be remembered that as long as N is in communication with the ground it cannot retain any free Electricity, and, therefore, under these circumstances the ball *n* can never be repelled; but as the free Electricity on P is dissipated a corresponding portion of the opposite Electricity must be liberated from N, and escape to the earth, and this action must go on till the entire charge is lost. But when *both* surfaces are *insulated*, as the free Electricity of P is absorbed by the atmosphere, a corresponding quantity of the opposite Electricity is liberated as before from N; but as it cannot now escape to the earth it becomes free Electricity, and repels the electroscope *n*. But this free Electricity becomes gradually absorbed by the air, and thus the entire charge is after a time dissipated.

(167) The arrangement of Electricity on a charged surface is strikingly shown by the following experiment introduced by Faraday.

A cylinder of gauze wire is placed on a plate of shell-lac; over it, but not resting on the lac, is placed another similar but larger gauze cylinder. These cylinders correspond with the coatings of a Leyden jar, the glass of which is represented by the intervening dielectric air: a small charge of Electricity is conveyed from the prime conductor of an electrical machine to the inner cylinder by means of a brass ball suspended by a silk thread. On now touching the *inner* coating of the *inner* cylinder with a disc of gilt paper insulated by a stick of lac, and then examining its condition by the torsion Electrometer, it is found to be neutral; but on passing the proof plane between the

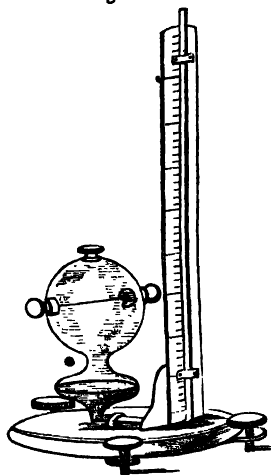
two cylinders, and touching the *outer* coating of the *inner* one, it brings away a charge of positive Electricity. In like manner, on touching the *outer* coating of the outer cylinder no Electricity is obtained; but from the *inner* coating a *negative* charge is transferred to the disc, which is rendered sensible by bringing the latter into contact with the electroscope.

These are simple consequences of Faraday's theory of static induction, (78, *et seq.*) The same general principles may be illustrated with a common Leyden phial, thus: let the jar (the outer coating of which is a little higher than the inner) be charged, and its ball and rod immediately removed by an insulating thread of white silk: now apply a carrier ball to either the inside or the outside coating; no signs of Electricity will be obtained, *the two forces being entirely engaged to each other by induction through the glass.* Now insulate the jar, and restore the ball and rod. Under these circumstances induction will take place through the air towards external objects, the tension of the polarized glass will fall, and the parts projecting above the jar will give electrical indications and charge the carrier; at the same time the *outside* coating will be found in the opposite electrical state, and *inductric* towards external surrounding objects, because a part of the force previously directed inwards will now be at liberty. The charge upon an insulated conductor in the middle of a room is, according to Faraday's views, in the same relation to the walls of that room as the charge upon the inner coating of a Leyden jar is to the outer coating of the same jar, one is not more *free* or *dissimulated* than the other; and when we sometimes make Electricity appear where it was not evident before, as in the above experiment upon the outside of a charged jar, when after insulating it we touch the inner coating, it is only because we divert more or less of the inductive force from one direction into another, for not the slightest change is in such circumstances impressed upon the character or action of the force, and the terms, "*free charge*" and "*dissimulated Electricity*," convey therefore erroneous notions if they are meant to imply any difference as to the mode or kind of action (*Ex. Resear.* 1682—1684). Harris entertains similar views: a coated jar, he says (*Phil. Trans.* 1834), may be considered as a sort of compound conductor in which the controlling effect of the insulated coating in respect of the electrometer is greatly increased by its proximity to the other in a free state, hence a much greater quantity may be accumulated on a given extent of surface with the same intensity. "The difference between electrical accumulation on coated glass and that on simple conductors is only in degree of effect, the laws incidental to the electrified substance remain the same."

(168) *Laws of electrical accumulation.* These have been minutely and successfully studied by Harris, the results of whose investigations are given in the *Transactions of the Plymouth Institution*, and in the *Transactions of the Royal Society*, 1834, 1836, 1839. The following is a brief *résumé* of some of his conclusions:—

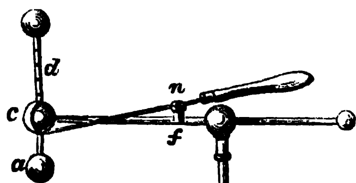
1°. Precisely the same charge accumulates on a coated surface whether we suppose the opposite coating to be insulated and connected with one of the conductors of the machine, or whether it be in a freely uninsulated state, or whether it operate through an intervening jar. In order to measure the force and extent of electrical accumulations, he employed an instrument which he calls the Electro-Thermometer, Fig. 94. It consists of an air thermometer through the bulb of which there is stretched, air tight, a fine platinum wire; the bulb is screwed, also air tight, on a small open vessel containing a coloured liquid, and soldered at the extremity of a long bent glass tube, to which is adapted a graduated scale: the fluid is adjusted to the zero of the scale by a small screw valve at the top of the bulb.

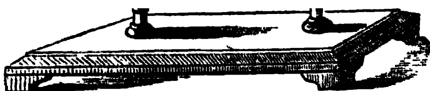
Fig. 94.



When an electrical accumulation is passed through the platinum wire it becomes more or less heated, expanding the air, and forcing the coloured fluid up the vertical tube, the height to which it ascends being measured on the scale. The delicacy of this instrument depends on the size of the platinum wire, which for ordinary purposes may be from the $\frac{1}{50}$th to the $\frac{1}{100}$th of an inch in diameter, and about 3 inches in length, corresponding with the diameter of the ball. The height to which the fluid rises is as the *square of the quantity of Electricity discharged.*

Fig. 95.





For transmitting the explosion through the wire the simple apparatus, shown in Fig. 95, was contrived. *c* is a brass ball supported on a rod of varnished glass passing through the mahogany ball *f*, supported on the glass pillar *g*. The ball *c* has a hole drilled vertically through its centre, so as to admit of the wire *d*, carrying at its lower end the discharging ball *d*, passing freely through it. The wire *d* has two or three small holes drilled in it by which it can be supported at a given height on the ball *c*, by means of a pointed bent wire attached to a hinge joint at *n*, and provided with an insulating handle. The ball *c* is in direct communication with the inside coating of the jar or battery, and the ball *b*, insulated on a stout pillar of glass, is connected in any required way with the outside coating. To effect the discharge the bent brass wire is liberated by a light touch of the glass handle, upon which the balls *d* and *b* come sharply into contact, transmitting the accumulation in a certain and invariable way without leaving any residuum in the battery.

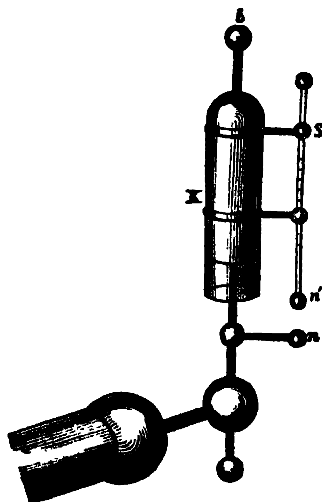
(169) A jar containing about five square feet of coated surface was charged with four turns of the machine, and then discharged through the Thermo-Electrometer: the fluid rose *nine* degrees. The jar was now placed on an insulating stand, and its external coating connected by a wire with the internal coating of a second and precisely similar jar, uninsulated and provided with a Lane's discharging Electrometer (Fig. 73). The Electro-Thermometer was likewise included in the circuit. After four turns of the machine the second jar discharged, and the fluid rose as before *nine* degrees. The small residuum in the second jar being removed (the first jar retaining its charge), the machine was again put in motion; after four turns the discharge of the second jar again took place, and the fluid again rose *nine* degrees. When the second jar was much smaller than the first, the explosion took place at about each turn of the plate till the large insulated jar was fully charged; and, as in both cases, the second jars were charged from the outer coating of the first, their explosions may be taken as fair measures of the relative quantities of Electricity communicated by the machine; and as these explosions correspond to equal numbers of revolutions, it follows that the accumulation in the insulated jar must have proceeded by equal increments, and consequently that equal quantities of Electricity were thrown on at each time. When several jars were substituted for the single jar, each being carefully insulated, the results were the same; and when two equal and similar jars were insulated, and one connected with the positive and the other with the negative conductor, their outer coatings being joined by a metallic rod, the effects of the accumulation in either system,

estimated as before at given intervals, were precisely similar, and corresponded to an equal number of turns of the plate, proving that the respective quantities which continued to accumulate in the opposite system after each discharge, must have been also precisely similar.

(170) From these experiments it appears: 1°. That equal quantities of Electricity are given off at each revolution of the plate to an *uncharged surface*, or to a surface *charged* to any degree short of saturation. 2°. That a coated surface receives equal quantities in equal times, and that the number of revolutions of the machine is a fair measure of the relative quantities of Electricity, all other things remaining the same. 3°. That the explosions of a second jar charged from the outer coatings of the first, are proportional to the quantity of Electricity thrown on the inner coating. The quantity of Electricity may therefore be easily and correctly estimated by the number of explosions.

(171) In accordance with these principles, Sir Wm. Harris constructed his Unit Jar, a little apparatus which he found of the greatest service to him in his subsequent investigations. It consists of a small jar, K, exposing about six square inches of coated surface,

Fig. 96.

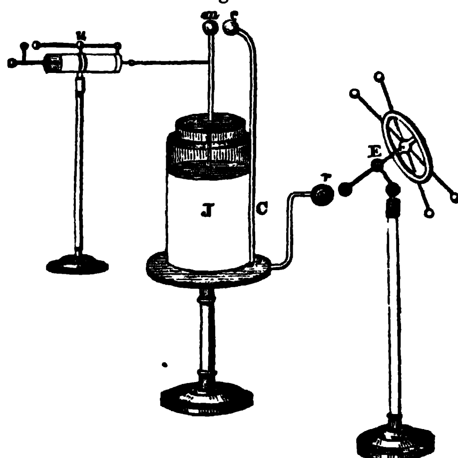


inverted on a brass rod fixed to the conductor of the machine, or otherwise sustained on a separate insulation; and the jar or battery to be charged is connected with its outer surface through the intervention of the brass ball *b*, as seen in Fig. 97. In this arrangement Electricity is continually supplied to the jar, and the amount

of accumulation accurately measured by the number of charges which the unit jar has received, the charges being determinable by means of the discharging balls *n n'*. By increasing or diminishing the distance between the discharging balls, the value of the unit may be rendered as great or as small as we please. Hence, if the balls be securely fixed, and the distance between their points of discharge accurately measured by means of a micrometer screw and index at S, comparative quantities may be always estimated and restored from time to time with a great degree of accuracy. (*Phil. Trans.* 1834, p. 217.)

(172) Much difference of opinion has existed amongst electricians as to whether this instrument is really a true measure of the *quantity* of Electricity thrown into a Leyden jar. The late Mr. Sturgeon (who was an excellent practical electrician), observes (*Lectures on Electricity*, p. 227): "After the first discharge has taken place, the resistance of the jar J (Fig. 97) against the

Fig. 97.



reception of fluid from the outside of the unit jar is increased, and the *discharging intensity* will be accomplished by a less quantity of fluid than at first; and this second discharge of the unit jar throws a still less proportion of the diminished quantity into J than in the previous discharge; and thus it is that each succeeding charge requires less and less fluid for the discharging intensity, and a corresponding disproportion enters the jar J. When the intensity of J becomes considerable, the unit jar will be nearly choked up, and incapable of receiving any but a very trifling quantity of fluid." Although however it is doubtless true that at each successive discharge of the unit jar when measuring into a jar or battery, the

outside of the unit jar becomes more and more charged, it seems clear that its *inner* surface must be also proportionately more charged each time before the balls connected with the coatings can have the relations requisite for discharge brought on; and in the discharge it is not the whole of the Electricity which passes, but just that portion which brings the inside and outside into equilibrium; and this will be the same quantity for every discharge. The jar is therefore a true measure as long as the circumstances of position, &c., are not altered. On this subject Professor Faraday has favoured us with the following remarks, which we gladly insert, as they seem to dispose satisfactorily of the whole question. After describing some experiments relating to the resistance or back action, he says: "The same difference will in every case exist between the balls *n n'*, Fig. 96, when a spark is ready to pass. Thus, suppose the unit jar has about one tenth of the electric capacity of the large jar J, Fig. 97, and that being charged up to its discharging point, it contains *ten* of positive Electricity; then these ten will pass on into the large jar as a discharge spark, and none will remain *within* the unit jar. Now, the conductor of the machine, the outside of the unit jar, and the ball and wire of the large jar, will all appear positive to a carrier ball. But when the machine is turned, although a rise in positive condition will gradually take place on all the surfaces, still the mutual relation of *n* and *n'* to each other will be *the same as before*, and the mutual relation of the inner and outer coating of the unit jar will be to each other *absolutely as before;* for no external relation can alter their *mutual* relation, though it may affect the outer coatings, both of the large jar and of the unit jar. So the machine must exert a higher charging power than before, which is shown by placing an Electrometer on its conductor; and when ten units have been thrown into J, then, if after the eleventh the machine conductor be discharged, the jar J will be discharged back between *n* and *n'*, because of the re-action backwards. Still, whenever a spark does pass from *n* to *n'*, the Electricity passing must be equal; because the inductive relations of the coatings to each other through the glass, and the like relations of the balls *n n'* to each other, remain absolutely the same. This is, as I think, a rigid consequence of the principles of inductive action."

(173) The free action of an electrical accumulation is estimated by the interval it can break through, and is ***directly proportional to the quantity of Electricity***. ***Experiment:*** Two similar jars, each containing five square feet of surface, being connected together, and with a Lane's discharging Electrometer (Fig. 73), the balls being set at $\frac{1}{10}$th of an inch apart, the discharge took place at the end of *two and a half* turns of the plate; the interval being doubled, the dis-

charge passed at the end of *five* turns; the interval being trebled, at *seven* turns; when the interval between the balls amounted to $\frac{4}{10}$ths of an inch, it required *ten* turns of the machine to produce a discharge.

(174) But the free action is *inversely proportional to the surface. Experiment:* One of the jars in the former experiment being removed, the balls being set at $\frac{4}{10}$ths of an inch, the discharge took place with *five* turns of the plate; the second jar being returned to its place, and the balls being set at $\frac{2}{10}$ths of an inch, the discharge again took place with five turns; and, on adding *two* more similar jars and setting the balls at $\frac{1}{10}$th of an inch, or one quarter the first distance, the discharge still took place with *five* turns.

(175) If however as the surface increases the Electricity increases also, *in the same ratio,* then the discharging interval remains the same; but if as Electricity is *increased* the surface is *diminished,* then the discharging interval is *directly as the square of the quantity of Electricity.*

Experiment: The balls of the Electrometer being set at $\frac{2}{10}$ths of an inch, the discharge of a single jar took place with $2\frac{1}{2}$ turns; a second similar jar being added, the balls remaining as before, the discharge took place with *five turns;* a third jar being added, with *seven* turns; two similar jars being used, the interval remaining the same, the discharge took place at five turns; but when one jar, i. e. half the surface was removed, and the balls set at $\frac{8}{10}$ths of an inch, the discharge occurred at *ten* turns. If we represent the quantity of Electricity by Q, the interval by I, and the surface by S, we get the following equation, $I = \frac{Q}{S}$, from which we get $Q = S\ I$, and thus derive another means of estimating the relative quantity of Electricity thrown upon a given surface, supposing the surface to be either in a divided or an undivided state, and all other things remaining the same.*

(176) The want of a correct knowledge of these laws has occasioned some uncertainty in electrical inquiries. Thus, in describing some experiments with his steel yard Electrometer (Fig. 74), Cuthbertson assumed *(Practical Electricity,* p. 175, 178, 179, 180), that when the slider had been set to 15 and 30 so as to measure separate charges, the surface being constant, the corresponding accumulations were in the same ratio, i. e. as 2 : 1; whereas, in order to obtain a double accumulation, the slider should be set to 60 instead of 30, since the opposing forces should be to each other as 4 : 1. It was assumed also by Singer *(Elements of Electricity,*

* In relation to this subject, see also Harris's experiments detailed in chap. ii.

p. 177), that the same quantity of Electricity will fuse the same length of wire, whether it be disposed on *two* jars or only on *one*, but in the experiment on which he relies for the demonstration of this, when the two jars were connected together, the slider of the Electrometer should have been set at 7½ grains instead of at 15 grains, because, as Harris has shown, when the same Electricity is disposed on a double surface, the intensity or free action is reduced to one-fourth; by setting the slider therefore at 15 grains, Singer nearly doubled the quantity of Electricity accumulated.

(177) When the same quantity of Electricity is disposed on the same extent of coated surface, divided into two or more equal parts, there is a gradual loss of power, till at last, when a given amount is disposed on a great number of jars, the effect on the wire of the Thermo-Electrometer becomes altogether insensible. Neither does the effect go on increasing in the same ratio with the quantity of Electricity and the number of jars; e. g. *double* the quantity of Electricity disposed on two jars does not produce *four times* the effect, as it would do if the Electricity in *one* jar only had been doubled, but only about *two and a half* times; the differences become more considerable as the number of jars is increased, till at length a limit appears to obtain, in which the advantage derived from an increased quantity becomes neutralized by the opposite effect, and the increased number of jars.

(178) The method of estimating the quantity of Electricity in jars and batteries by the fusion of wires as employed by the older electricians, and also to a great extent by Cuthbertson and Singer is very uncertain, since wires may become fused with but little difference in appearance when very different quantities are passed through them (*Singer*, p. 180); besides which, it is very difficult to ascertain with precision the point at which fusion takes place, so that the wire may be just made red hot through the whole length and then drop into balls (*Cuthbertson*, p. 180). The practice also of moistening the interior of jars by breathing into them, leads to great uncertainty in accurate experiments. It is in fact little more than an ingenious method of increasing the inner coating in such a way as to extend the surface, as to increase the quantity of Electricity, the attractive force of the free action remaining the same. The heating effects however of given quantities of Electricity discharged under the same conditions through a metallic wire are always the same, whatever may have been its previous tension or intensity (145) relating to the conductors on which the accumulation has taken place; e. g. a given quantity of Electricity accumulated on coated jars always produces the same effect on the wire of the Electro-Thermometer (Fig. 94),

whether accumulated on thick glass or on thin, or on a greater or less extent of surface, the number of jars and the length of the circuit being the same. Harris found, however, that the effects of given quantities of Electricity discharged through the Electro-Thermometer varied with the *resistance*, being less with a long circuit than with a short one, and varying in an *inverse ratio* of the length.

(179) By varying the striking distance between the balls of Lane's Electrometer, no variation in the effects on the wire of the Thermometer occurs, even when the striking interval is made very considerable by enclosing the balls in the receiver of an air pump and exhausting the air, so long as the quantity of Electricity remains the same. The effect of exhausting the air however is to facilitate the discharge, e. g. when the density of the air is diminished to one-half, the discharge occurs with *one-half* of the quantity accumulated; that is, with *one fourth* of the intensity or free action, and the distance through which a given accumulation can discharge is in an inverse simple ratio of the density of the air; e. g. in air of one-half the density, the discharge occurs at *twice* the distance; in other words, the resistance of the air is as the *square of the density directly*. From this it would appear that in air highly rarefied, as in the upper egions of the atmosphere, no considerable electrical accumulations can take place; and one of the most beautiful experiments in Electricity is to pass discharges through long distances in rarefied air, by which exact imitations of summer lightnings are produced.

(180) The resistance to discharge in air (a non-conductor) is of a different nature to the resistance offered by conducting bodies; in the former it arises solely from the pressure of non-conducting particles, and when the attractive forces are sufficiently great to overcome the resistance, the discharge passes without regard to distance. Harris found also that the restraining power of air is not affected by heat; the discharge between two balls in an air-tight receiver taking place, with precisely the same quantity of accumulation at all temperatures between 50° and 300° Fah. The insulating power of air depends therefore solely on its density, and it would appear also that heat (if material) must be a non-conductor of Electricity, since it does not in the least degree impair the insulating power of air.

(181) The supposed *conducting power* of a vacuum is unphilosophical, as a space free from all matter can scarcely be said to have any positive qualities whatever; the reason an electrified body discharges to a conducting body *in vacuo* more readily than in air is, because there is less restraining power in consequence of non-conducting particles of air. The discharge does not however occur in

consequence of any tendency of the electric principle to evaporate, but solely because of the removal of the obstructions interposed between the points *from*, and *toward* which, the accumulated Electricity tends to flow, and if the density of air could be *indefinitely* diminished, and the distance between the points of action *indefinitely* increased, we should in all probability eventually have the same relative electrical state continued without dissipation.

(182) Such are some of the important principles of electrical action, established by the researches of this able and indefatigable Electrician. A brief recapitulation of the results may be, in conclusion, useful.

1°. An electrical accumulation proceeds by equal increments; a coated surface receiving equal quantities in equal times, all other things remaining the same, and the quantity of Electricity passing from the outer coating is always proportional to the quantity added to the inner.

2°. The quantity of Electricity accumulated may be measured by the revolutions of the plate, or by the explosion of a jar connected with the outer coating. It is as the surface multiplied by the interval the accumulation can pass. When the *surface* is constant, it is as the *interval*; when the *interval* is constant, it is as the *surface*. It is also as the surface multiplied by the square root of the free action; when therefore the surface is constant, it is as the *square root* of the attractive force.

3°. The interval which the accumulation can pass is directly proportional to the quantity of Electricity, and inversely proportional to the surface; it is as the quantity divided by the surface. If the Electricity and surface be either increased or decreased in the same proportion, the interval remains the same. If as the Electricity is increased, the surface be decreased, the interval will be as the square of the quantity of Electricity.

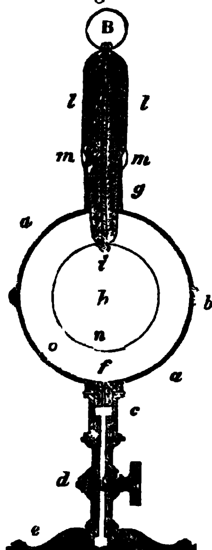
4°. The force of electrical attraction varies in the inverse ratio of the squares of the distance between the points of contact of the opposed conductors, supposing the surfaces to be plane and parallel: or otherwise, between two points which fall within the respective hemispheres, at a distance equal to one-fifth of the radius, supposing the opposing surfaces to be parallel.

5°. The free action is in *direct proportion* to the square of the quantity of Electricity, and in *inverse proportion* to the square of the surface. It is directly as the effect of the explosion on a metallic wire, all other things remaining the same. If the Electricity and surface increase or decrease together, and in the same proportion, the attractive force remains the same. If as the Electricity is

increased the surface is decreased, the attractive force is as the *fourth power* of the quantity of Electricity.

6°. The effect of an electrical explosion on a metallic wire depends *exclusively on the quantity of Electricity*, and is not influenced by the intensity or free action; it is diminished by accumulating the Electricity on a divided surface; it is as the *square* of the quantity of Electricity. It is as the square of the interval which the accumulation can pass; it is directly as the attractive force and the free action, all other things remaining the same; it is as the momentum with which the explosion pervades the metal.

Fig. 98.



(183) *Specific inductive capacity.*—It was with an apparatus constructed on the principles of the Leyden phial, that Faraday succeeded in proving by the most decisive experiments that *induction has a particular relation to the different kinds of matter through which it is exerted.* A section of this ingenious apparatus is shown in Fig. 98. *a a* are the two halves of a brass sphere, with an air-tight joint at *b*, like that of the Magdeburgh hemispheres, made perfectly flush and smooth inside, so as to present no irregularity; *c* is a connecting piece, by which the apparatus is joined to a good stop-cock *d*, which is itself attached either to the metallic foot *e*, or to an air-pump. The aperture within the hemisphere at *f* is very small: *g* is a brass collar fitted to the upper hemisphere, through which the shell-lac support of the inner ball and its stem passes: *h* is the inner ball, also of brass; it screws on to the brass stem *i*, terminating above by a brass ball B; *l l* is a mass of shell-lac, moulded carefully on to *i*, and serving both to support and insulate it and its balls *h* B. The shell-lac stem *l* is fitted into the socket *g* by a little ordinary resinous cement more fusible than shell-lac applied at *m m*, in such a way as to give sufficient strength and render the apparatus air-tight there, yet leave as much as possible of the lower part of the shell-lac stem untouched as an insulation between the ball *h* and the surrounding sphere *a a*. The ball *h* has a small aperture at *n*, so that when the apparatus is exhausted of one gas and filled with another, the ball *h* may also itself be exhausted and filled, that no variation of the gas in the interval *o* may occur during the course of an experiment.

(184) The diameter of the inner ball is 2·33 inches, and that of the surrounding sphere 3·57 inches. Hence the width of the intervening

space through which the induction is to take place is 0.62 of an inch; and the extent of this place or plate, *i.e.* the surface of a medium sphere, may be taken as 27 square inches, a quantity sufficiently large for the comparison of different substances. Great care was taken in finishing well the inducing surfaces of the ball *h* and sphere *a a*, and no varnish or lacquer was applied to them, or to any part of the metal of the apparatus.

(185) When the instrument was well adjusted, and the shell-lac perfectly sound, its retentive power was found superior to that of Coulomb's Electrometer, *i. e.* the proportion of loss of power was less. A simple view of its construction shows that the intervening dielectric or insulating medium may be charged at pleasure with either solids, liquids, or gases; and that it is admirably adapted for investigating the specific inductive capacities of each.

(186) Two of these instruments, precisely similar in every respect, were constructed; and the method of experimenting was (different insulating media being within) to charge one with a Leyden phial, then, after dividing the charge with the other, to observe what the ultimate conditions of each were. For a detailed account of the method of manipulating, and the precautions necessary to obtain accurate results, we must refer to the original paper of the author (*Experimental Researches*, Eleventh Series, 1187 *et seq.*)

(187) The question to be solved may be stated thus: suppose *a* an electrified plate of metal suspended in the air, and *b* and *c* two exactly similar plates, placed parallel to and on each side of *a* at equal distances and uninsulated; *a* will then induce equally towards *b* and *c*. If in this position of the plates some other dielectric than air, as shell-lac, be introduced between *a* and *c*, will the induction between them remain the same? Will the relation of *c* and *b* to *a* be unaltered notwithstanding the difference of the dielectrics interposed between them? (*Exp. Resear.* 1252.)

(188) The first substance submitted to examination was shell-lac, as compared with air. For this purpose a thick hemispherical cap of shell-lac was introduced into the lower hemisphere of one of the inductive apparatus, so as nearly to fill the lower half of the space between it and the lower ball. The charges were then divided (186), each apparatus being used in turn to receive the first charge before its division by the other; and as it had previously been ascertained that both the instruments had equal inductive power when air was in both, it was concluded that if any difference resulted from the introduction of the shell-lac, a peculiar action in that substance would be proved, and a case of specific inductive influence made out.

(189) On making the experiment with all the care and attention

that could be bestowed, an extraordinary and unexpected difference appeared, and the conclusion was drawn that the specific inductive capacity of shell-lac as compared with air is as 2 to 1. With glass a result came out, showing its capacity compared with air to be as 1·76 to 1; and with sulphur a result showing its capacity to be as 2·24 to 1. With this latter substance the result was considered by Faraday as unexceptionable, it being, when fused, perfectly clear, pellucid, and free from particles of dirt, and being moreover an excellent insulator.

(190) Liquids, such as oil of turpentine and naphtha, were next tried; and though no good results could be obtained, on account of their conducting power, they were nevertheless considered by Faraday as not inconsistent with the belief, that oil of turpentine, at least, has a specific inductive capacity greater than air.

(191) Air was then tried, but no alteration of capacity could be detected on comparing together, rare and dense, hot and cold, or damp and dry: then all the gases were submitted to examination, being compared together in various ways, that no difference might escape detection, and that the sameness of result might stand in full opposition to the contrast of property, composition, and condition, which the gases themselves presented; nevertheless not the least difference in their capacity to favour or admit electrical induction through them could be perceived.

(192) During the experiments with shell-lac (188), Faraday first observed the singular phenomenon of the *return charge*. He found, that, if, after the apparatus had been charged for some time, it was suddenly and perfectly discharged, even the stem having all Electricity removed from it, it gradually recovered a charge which in nine or ten minutes would rise up to 50° or 60°. He charged the apparatus with the hemispherical cap of shell-lac in it, for about forty-five minutes, to above 600° with positive Electricity at the balls *h* and B, Fig. 98, above and within. It was then discharged, opened, the shell-lac taken out, and its state examined by bringing the carrier ball of Coulomb's Electrometer near it, uninsulating the ball, insulating it, and then observing what charge it had acquired. At first the lac appeared quite free from any charge, but gradually its two surfaces assumed opposite states of Electricity, the concave surface, which had been next the inner and positive ball, assuming a positive state; and the convex surface which had been in contact with the negative coating, acquiring a negative state; these states gradually increasing in intensity for some time.

(193) Glass, spermaceti, and sulphur, were next tried, all of them exhibited the peculiar state after discharge. Faraday also sought to produce it without induction, and with *one* electric power, but failed

in doing so; a fact in favour of the inseparability of the two electric forces, and an argument in favour of the dependence of induction upon a polarity of the particles of matter.

(194) Faraday was at first inclined to refer these effects to a peculiar masked condition of a certain portion of the forces, but he afterwards traced them to the known principles of electrical action. He took two plates of spermaceti and put them together, so as to form a compound plate, the opposite sides of which were coated with metal. The system was charged, then discharged, insulated, and examined, and found to give no indication to the carrier ball: the plates were then separated, when the metallic linings were found in opposite electrical states. Hence, it is clear that an actual penetration of the charge to some distance within the dielectric, at each of its two surfaces, took place by conduction: so that, to use the ordinary phrase, the electric forces sustaining the induction are not upon the metallic surfaces only, but upon and within the dielectric; also extending to a greater or smaller depth from the metal linings.

(195) The following explanation may be offered:—Let a plate of shell-lac, six inches square, and half an inch thick, or a similar plate of spermaceti, an inch thick, coated on the sides with tin-foil, as in the Leyden phial, be charged in the usual manner, one side positively and the other negatively. After the lapse of ten minutes, or quarter of an hour, let the plate be discharged and immediately examined; no Electricity will appear on either surface, but in a short time, upon a second examination, they will appear charged in the same way, though not in the same degree as they were at first. Now, it may be supposed, that under the coercing influence of all the forces concerned, a portion of the positive and negative forces has penetrated and taken up a position within the dielectric, and that consequently, being nearer to each other, the induction of the forces towards each other will be much *greater*, and that, in an external direction, *less* than when separated by the whole thickness of the dielectric; when, however all external induction is neutralized by the discharge, the forces by which the electric charge was driven into the dielectric are at the same time removed, and the penetrated Electricity returns slowly to the exterior metallic coatings, constituting the observed re-charge. According to Faraday, it is the assumption for a time, of this charged state of the glass, between the coatings of the Leyden jar, which gives origin to a well-known phenomenon, usually referred to the diffusion of Electricity over the uncoated portion of the glass, namely, the *residual charge*. After a large battery has been charged for some time, and then discharged, it is found that it will spontaneously recover its charge to a very consi-

derable extent, and by far the largest portion of this is referred to the return of Electricity in the manner described.

(196) The relation of induction to the matter through which it is exerted, is well shown as a class experiment, by the following apparatus. Three equal discs of brass are arranged parallel, and at equal distances from each other: the two exteriors are in communication with the ground, the third which is between them is insulated; a small single leaf Electroscope is suspended equidistant between two brass balls, each of which communicates separately with one of the exterior discs. The middle disc is charged with a certain quantity of Electricity, and the connection of the two exterior discs with the ground is cut off. If the gold leaf is exactly equidistant between the two balls (which is absolutely essential to the success of the experiment), it will remain at rest, being equally attracted by each of the balls, which, being in communication with the exterior discs, are equally electrized by induction. As thus arranged, the insulating stratum that separates the three discs is *air;* but if for one of these strata one of *shell-lac*, *glass*, *sulphur*, or any other insulator be substituted, the gold leaf immediately diverges, showing that the inducing action of the electrized body upon the disc, from which it is separated by the new insulating body, has become greater. This simple method of demonstrating Faraday's great discovery originated with Matteucci. (*Elect. Mag.* vol. ii. p. 186.)

Some of Matteucci's later experiments gave him results which induced him to doubt the accuracy of the explanation, given by Faraday, of the part played by insulating bodies in the phenomena of induction of static Electricity. He affirms that the insulating power of a body, consists in the greater or less resistance opposed by bodies to the destruction of that molecular polarization, which is always developed in it during the presence of an electric body; that the differences in insulating plates of different substances are not due to a specific inductive power, but to differences in the propagation of Electricity, either at the surface, or in the interior, of the bodies, and that the Electricity which penetrates into their interiors and which is diffused over their surfaces, returns on the instant to the surface, when it is covered with a metal plate in communication with the ground. The experiments on which he founds these opinions are certainly striking ones. He introduced insulating plates of different substances by means of insulating stems into the case of a Coulomb's balance having its two electrized balls divergent, and he found that the ball experienced the same loss of Electricity, whether touched by gum-lac, or sulphur, or by glass covered with a coat of gum-lac varnish $\frac{1}{100}$ of an inch thick; and by constructing a kind of box of mica, the

interior surface of which was covered with lac varnish, he compared together air, sulphur, glass, and gum-lac; and found the effects the same in each.

(197) *Lateral discharge.*—When a large jar or battery is discharged by a metallic wire held in the hand, without the protection of an insulating handle, a slight shock is frequently felt in the hand that grasps the wire: and if a large jar be placed on a table, with its knob in contact with the prime conductor, and if a chain be stretched upon the table, with one end nearly touching the outside coating of the jar, by charging the apparatus till it discharges itself voluntarily, a spark is seen to pass between each link of the chain, which thus becomes illuminated, though it forms no part of the circuit.

This spark is called the *lateral discharge;* it is occasioned by a small excess of free Electricity, which distributes itself over a discharging surface, when a charged system is discharged or neutralized. It arises from the fact, satisfactorily established by Harris, and acknowledged by Biot, Henry, and others, that the accumulated Electricity is never exactly balanced between the opposed coatings; so that there will always be an excess of positive or negative Electricity *over* the neutralizing quantities themselves, disposed on the coatings of the jar. The existence of this excess of Electricity, either positive or negative, is proved by the fact, that if we charge a jar, allow it to remain insulated, and discharge it gradually, by drawing sparks from the knob, and adding them to the outer coating, we can always take a *finite* spark from either side alternately, whilst the jar rests on the insulator.

If we place a charged jar upon an insulating stand, and discharge it in the usual manner, with a discharging rod, the excess of free Electricity exhibits itself in the form of a spark, at the moment of discharge between any body connected with the outer coating, and another in communication with the earth: the intensity of the spark depends on the capacity of the jar, being *less* with a large jar, and *greater* with a small one; the quantity of Electricity discharged being the same (Harris). After the discharge, the knob, outer coating, and all bodies connected with the jar, are found in the same electrical state, which we may make either positive or negative, by taking a spark either from the knob or coating, previously to discharging the jar.

This small quantity of free Electricity may be obtained even when the jar is connected with the earth, provided we seize it before the conductors have time to carry off the residuary accumulation; it having been proved by Professor Wheatstone, that some portion of time elapses in the passage of Electricity through wires: the effect,

however, is greatest when the jar and its appendages are quite insulated.

(198) The following experiments convey a good deal of information respecting the nature of the so-called *lateral discharge*.

Ex. 1. Let the jar J. (Fig. 97), be charged *positively*, removed from the machine and insulated; under this condition discharge it. When discharged, let the electrical state of the knob *m*, discharging conductor *e* C, and the outer coating J, be examined; they will all be found in the same electrical state, which state will be precisely that exhibited by the outer coating and knob, whilst charging, and the small residuary charge will be *plus*.

Ex. 2. Charge the jar as before; but before discharging it withdraw the free Electricity from the knob. The electrical state of the coating and appendages will now be changed, and the small residuary spark will be *minus*—thus showing that the Electricity of the spark varies with the coatings.

Ex. 3. Immediately *after* the discharge, apply a metallic body to the coating J; a residuary spark will be thrown off, which spark obviously cannot be caused by any lateral explosion caused by the discharging rod.

Ex. 4. After this residuary spark has been taken from the outer coating, examine the jar, and it will be found again slightly charged as at first, showing the spark to be merely a residuary accumulation.

Ex. 5. Charge a jar, exposing about two square feet of coating, with a given quantity of Electricity, measured by the unit jar *u*, let a conducting rod terminating in a ball *r* project from the outer coating, and place near it the electroscope E. Discharge the jar through the rod *c c* as before, and observe the amount of divergence of the electroscope. Double the capacity of the jar, and again accumulate and discharge the same quantity. The divergence of the electroscope will be very considerably decreased: add a second and a third jar to the former, and the effect will be at last scarcely perceptible: connect the jar with the ground, and with a given quantity the spark will vanish altogether.

Ex. 6. Accumulate a given quantity as before, and observe the effect of the residuary charge on the electroscope. Let a double, treble, &c., quantity be accumulated and discharged from a double, treble, &c., extent of surface—that is to say, for a double quantity employ two similar jars and so on; the effect will remain the same.

These two last experiments prove that the spark is of different degrees of force when the Electricity is discharged from a greater or less extent of surface, whilst double, treble, &c., quantities, when discharged from double, treble, &c., surfaces, give the same spark.

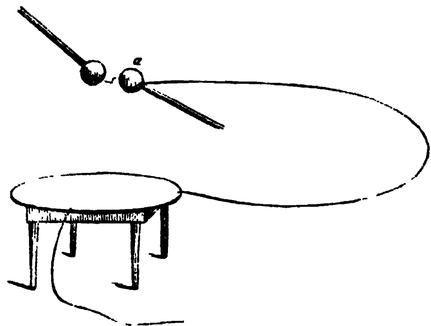
Now, as no one can doubt but that the effect of a double, &c., quantity should be greater than a single, &c., quantity, it is again evident that the spark is not caused by any lateral explosion from the discharging rod, it being a well-established law that the same quantity has the same heating effect on wires, whether discharged from a great surface or a small one, from thick glass or thin; some little allowance being made for the greater number of rods, &c., when the surface is increased by an additional number of jars. The effect, therefore, depends on the jar.

Ex. 7. Discharge a jar by means of discharging circuits of different dimensions, from a large rod down to a fine wire, which the charge in passing can make red-hot. Observe the effect on the electroscope in each case: it will be found nearly the same, being rather less where the tension in the discharging wire is very considerable—proving that the tension on the rod is not of any consequence.

Ex. 8. Connect the jar with the ground, and place a small quantity of percussion powder enclosed in thin paper between the discharging conductor *c*, Fig. 97, and a metallic mass placed near it. The powder will not be inflamed even in the case of the discharging conductor becoming red-hot, whereas in passing the slightest spark it inflames directly, which shows that no kind of lateral action arises during the passage of the charge.

Ex. 9. Let a circular piece of wood between two and three feet in diameter be covered with tin-foil, placed on a stool, and connected with the earth as shown in Fig. 99. Let sparks be now taken between the prime conductor and the ball *a*. Lateral sparks may always be obtained from the wire whenever a conductor is approached to it. By connecting a stout copper wire with the gas fittings of the house, insulating it on glass rods at different parts of the room, and drawing sparks from the prime conductor of the large Polytechnic machine by means of a brass ball five inches in diameter attached to the other end of the wire, and held in an assistant's hand by means of a glass rod, Mr. Walker obtained sparks not only from the gas fittings of the room in which the experiments were made, but also from the burners in the workshops *two stories below*. It does not, however, require a machine

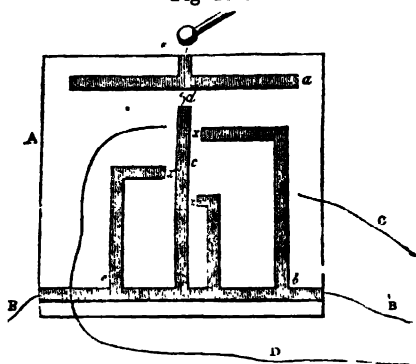
Fig. 99.



of very great power to exhibit such phenomena; we have frequently inflamed hydrogen gas from a jet attached to a bladder by directing the stream against a gas pipe in a room adjoining one in which sparks were being drawn from the conductor of a machine the plate of which is 30 inches in diameter..

Ex. 10. The following instructive experiment was arranged by Dr. Bachhoffner.

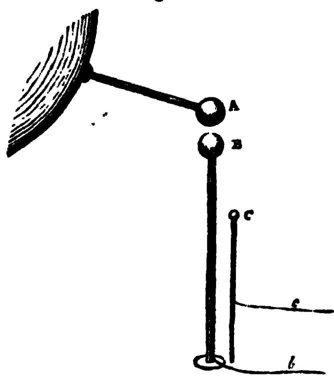
Fig 100.



On a deal board, about two feet square, were pasted slips of tin-foil *a b c*, Fig. 100. Sparks were passed from the machine upon *a*, from which they discharged themselves at *d*, to the conductor *c*, and passed along it to B; but under no circumstances would they pass the spaces *x x x*, on which was placed percussion powder. The wire B was now removed to the position 'B, connecting it with a good discharging train, and the experimenter took in his hand the wire C, connected with the same pipes, and in the same direction sparks were passed as before at *d*, and by applying the wire C to any part of the slips of tin-foil, he was enabled to draw off sparks; but when the wire C was placed in a position similar to that represented by D, *touching the tin-foil b* at *e*, the sparks ceased to appear.

Ex. 11. Let a long brass rod, terminating in the ball A, Fig. 101, be connected with the prime conductor of a large machine in vigorous action; let a corresponding ball B be mounted on a similar rod, and screwed into a small brass plate fixed to the floor of the room. Let the stout wire *b* connect the plate with a good discharging train, while a smaller brass rod *c*, terminating in a brass ball is connected with the same discharging train by the stout wire *c*. Put the machine in action, and allow a series of long and vivid sparks to pass between A and B. As long as the rod *c* rests on the brass plate, no sparks will occur

Fig. 101.



between it and the rod B; but when *c* is moved into the position represented in the figure, that is, when its lower end is made to rest on the floor of the room, long and bright sparks will pass in abundance from the rod B, and this whether the wire *b* be or be not attached to the smaller rod. *Here* the reason why sparks are not obtained between B and C, while the latter rests on the brass plate, is because the resistance in the direction B *b* is *less* than in the direction B C *c*, and sparks *are* obtained when the rod *c* does not touch the brass plate because the resistance in the direction B C *c* is less than in the direction B *b*.

(199) The lateral discharges thrown off by a wire leading from a ball in the act of receiving dense sparks from an electrical machine, result from the inductive action of the Electricity accumulated on the conductor upon the vicinal conducting substances, which completing the terminating surfaces of a charged system, determines the charging of the stratum of air between them, and sparks will consequently strike off from the wire to these free conducting bodies as long as sparks continue to pass between the two conductors. If the wire from which these lateral explosions proceed be connected directly with the machine, the phenomena disappear; because the accumulation on the conductor is prevented from reaching any great intensity; it is necessary therefore to employ disruptive discharges between opposed conductors, and the larger the surface of the charged conductor the greater is the effect produced.

(200) By the following instructive experiments it has been proved by Harris, that an electrical explosion will not leave a good conductor constituting an efficient line of action, to fall upon bodies out of that line :—

Lay some small pieces of gold-leaf on a piece of paper, as represented in Fig. 102, pass a dense shock of Electricity (from not less than eight square feet of coating) over these, from the commencement at A to the termination at B, so as to destroy the gold: the line which the discharge has taken will be thus shown by the blackened parts, and the result will be as in Fig. 102, which is copied from the actual effects of the electrical discharge. By the result of the explosion represented in Fig. 103, it is shown that the portions of the conductor below the striking parts are out of the line of discharge, and not involved in the result.

(201) In Fig. 102 it is particularly worthy of remark, that not only are the pieces 5, 6, 14, 15, 18, 19, 22, 23, untouched, being from their positions of no use in facilitating the progress of the charge, but even portions of other pieces which have so operated are left perfect, as 2, 3, 8, 9, 10, &c.; so little is there any tendency to a

Fig. 102.

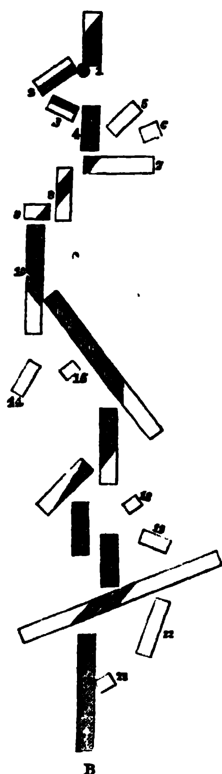
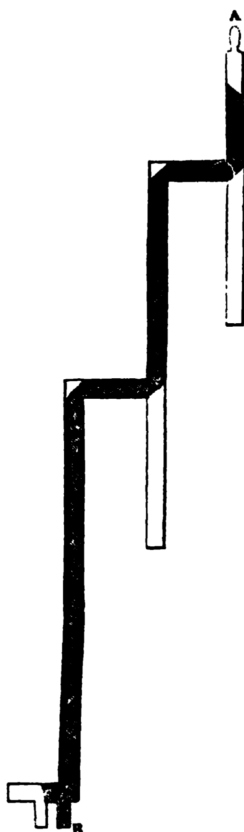


Fig. 103.



lateral discharge even up to the point of dispersion of the metallic circuit in which the charge has proceeded: indeed, as Harris observes, so completely is the effect confined to the line of least resistance, that percussion powder may be placed with impunity in the interval between the portions 4, 5, and he contends that the separate pieces of gold leaf thus placed may be taken to represent detached conducting masses fortuitously placed along the mast and hull of a ship, and that therefore any fear that a conductor on a ship's mast would operate on the magazine is quite unwarranted.

(202) *Physiological effects.*—The sensation experienced, when the body is made a part of the electrical circuit, is now so universally known, that a description here would be superfluous. The exaggerated accounts of their feelings, on the first transmission of a discharge through the bodies of the first experimentalists, was alluded to in the first chapter. It is not, however, easy to explain the cause

of the muscular contraction that is experienced. The involuntary action may be produced by the concussion of a material agent (?) passing through the body, by an influence on the nervous system, or by a sudden disturbance of the electric equilibrium: and the dull pain at the joints is probably to be traced to the resistance which the force experiences in passing from one bone to another.

(203) It is stated by Mr. Morgan, that, if a strong shock be passed through the diaphragm, the sudden contraction of the muscles of respiration will act so violently on the air of the lungs, as to occasion a loud and involuntary shout; but that a small charge occasions in the gravest person a violent fit of laughter: persons of great nervous sensibility are affected much more readily than others.

A small charge sent through the spine instantly deprives the person for a moment of all muscular power, and he generally falls to the ground. If the charge be very powerful, instant death is occasioned. Mr. Singer states that a charge passed through the head gave him the sensation of a violent and universal blow, which was followed by transient loss of memory and indistinctness of vision. A small charge sent through the head of a bird will so far derange the optic nerve as to produce permanent blindness; and a coated surface of thirty square inches of glass will exhaust the whole nervous system to such a degree as to cause immediate death. Animals the most tenacious of life are destroyed by energetic shocks passed through the body. Van Marum found that eels are irrecoverably deprived of life when a shock is sent through their whole body: when only a part of the body is included in the circuit, the destruction is confined to that individual part, while the rest retains the power of motion.

The bodies of animals killed by lightning are found to undergo rapid putrefaction; and it is a remarkable circumstance, that after death the blood does not coagulate. Some remarkable cases of electrical excitement are related by Loomis (*American Journal of Science*, 1850, p. 320), as having been observed in several houses in New York, when individuals received shocks on touching the handles of the doors, and other metallic bodies, and even on shaking hands, and kissing, and he arrived at the conclusion after a careful examination, that the Electricity was excited by the friction of the shoes of the inmates, upon the carpets of the house, which were entirely of wool and of close texture.

(204) When the Leyden phial was first discovered, it was imagined that an agent of almost unlimited medical power was raised, and it was applied indiscriminately for the most opposite diseases. The failure consequent on such quackery brought Electricity into disrepute, and for a long time it was discarded almost entirely from our

hospitals. It is now again more generally employed, and has been found of great service in many cases, such as palsy, contractions of the limbs, rheumatism, St. Vitus's dance, some kinds of deafness, and impaired vision. It is administered in five different ways:—1st, under the form of a gentle stream or aura, from a pointed piece of wood provided with an insulating handle, and communicating with the prime conductor: by this means it may be directed to parts of great sensibility, as the eye. 2nd, by causing the part to be operated upon to draw sparks from the prime conductor; or placing the patient on a stool with glass legs, by drawing sparks from him with a metallic ball. 3rd, by the transmission of shocks, which is the most severe and painful, and which requires great caution. 4th, by galvanism. And 5th, by electro-magnetism and magneto-electricity, both of which latter methods will be described in future chapters.

(205) There can be no doubt that Electricity is very materially concerned in the economy both of animal and vegetable life, but we possess no precise information on the subject. It is not improbable that it may have something to do with the rise of sap, from the fact that Electricity always increases the velocity of a fluid moving in a capillary tube. On vegetables strong shocks have the same effects as on animals, namely, produce death: a very slight charge is sufficient to kill a balsam. It may further be observed that living vegetables are the most powerful conductors with which we are acquainted. Mr. Weekes found that a coated jar, having 46 inches of metallic surface, was repeatedly discharged by the activity of a vegetable point, in 4 min. 6 sec.; while the same jar, charged to the same degree, required 11 min. 6 sec. to free it from its electric contents by means of a metallic point: the points in both cases being equidistant. The same gentleman also found that the gold-leaf electroscope is powerfully affected by a jar at the distance of nearly seven feet, when the cap of the instrument is furnished with a branch of the shrub called *butcher's broom;* though the same instrument, when mounted with pointed metallic wires, is not perceptibly affected until the charged jar approaches to within two feet of the cap.

If a blade of grass and a needle be held pointing towards the prime conductor of a machine, while the person holding them recedes from the instrument, a small luminous point will appear on the apex of the grass long after it has vanished from the apex of the needle.

(206) The following experiment was made by Pouillet, who drew from it the conclusion that a considerable portion of the Electricity with which the atmosphere is loaded is derived from the gaseous fluids given out by plants during the process of vegetation. But it is right to mention that the experiments of Sir H. Davy (*Phil. Trans.*

for 1826, p. 398) are rather inconsistent with that of the French electrician.

M. Pouillet arranged in two rows beside each other, on a table varnished with gum-lac, twelve glass capsules, each about eight inches in diameter, coated externally for two inches round the lips with a film of lac varnish: they were filled with vegetable mould, and were made to communicate with each other by metallic wires, which passed from the inside of one to the inside in the next, going over the edges of the capsules. Thus the inside of the twelve capsules and the soil which they contained formed only a single conducting body. One of these capsules was placed in communication with the upper plate of a condenser by means of a brass wire; while at the same time the under plate was in communication with the ground.

Things being in this situation, and the weather very dry, a quantity of corn was sown in the soil contained in the capsules, and the effects were watched. The laboratory was carefully shut, and neither fire, nor light, nor any electrified body, was introduced into it. During the first two days, the grains swelled, and the plumulæ issued out about the length of a line, but did not make their appearance above the surface of the earth. But on the third day the blades appeared above the surface, and began to incline towards the window, which was not provided with shutters. The condenser was now charged with *positive* Electricity; consequently, the carbonic acid gas which disengages itself during the germination of the seed is charged with positive Electricity, and is therefore precisely in the same state as the carbonic acid formed by combustion. This experiment was repeated several times with success. But the Electricity cannot be recognised unless the weather is exceedingly dry, or unless the apartment is artificially dried by introducing substances which have the property of absorbing moisture.

These capsules being insulated, and the air being very dry, and the soil so dry that it is an imperfect conductor, it is evident that the Electricity would be retained. Accordingly, when the condenser was brought into a natural state after one observation, and then re-placed for experiment, during one second only, it was found to be charged with Electricity.

(207) Mr. Pine, of Maidstone, describes the following experiment,* made to determine the influences of Electricity on germination:—A few grains of mustard seed were sown in similar soils contained in Leyden jars, electrified positively and negatively. In four days the plants issued from the soils in both jars; but those in the negative jars were most advanced. Plants under ordinary circumstances did

* Proceedings of the Electrical Society, Part III. p. 163.

not appear till about two days later. In fourteen days from the time of sowing, the plants in the negative jar had grown to 2¾ inches, those in the positive jar to 2¼ inches, and those in the ordinary state to 1⅛ inches. The jars in these experiments were uninsulated, for the purpose of allowing a slight current of fluid to pass through the plants.

The following experiment was made by Mr. Weekes:—In two small flower-pots, filled with rich mould, a few grains of mustard-seed were sown; both were kept gently watered, but one pot was *insulated* and frequently electrified under circumstances which kept it, as it were, in an electrified atmosphere. The other pot was not interfered with, and the result was, that the vegetation of the electrified seeds appeared several days before the others, and continued afterwards to grow with a much greater degree of vigour. The Electricity employed was derived from a galvanic arrangement of thirty pairs of plates, charged with salt water.

(208) It will be proper to mention, however, that the experiments undertaken by the author have failed to show any advantage in favour of electrified soil. Amongst them were the following:—Three small metallic cups were filled with fine vegetable mould, and in each a few seeds of mustard were sown. The soil in each was uniformly moistened with water. Two of the cups were insulated and kept constantly electrified by two batteries of twenty pairs of 5-inch plates, charged with pump-water, the current being made to pass *down* the soil in one cup, and *up* the soil in the other. The third cup was unelectrified. On the third day, the *unelectrified* seeds had germinated, and appeared above the surface of the mould. On the morning of the fourth day, the young plants were fully developed; but in the seeds in the electrified cups, germination had only just commenced. In this experiment, therefore, Electricity, instead of favouring, appeared actually to retard germination.

Three small garden-pots were then filled with the same soil, and mustard seed being sown in each, they were placed side by side in glass basins containing a little water. Two of them were then kept electrified by the same batteries as before, the wires passing about half an inch into the soil at the surface, and through the holes at the bottom of the pots. On the morning of the third day, germination had commenced in all the pots: on the fourth day, the young plants were all out of ground: at the end of a week they were fully developed, but there was not the slightest advantage in favour of those which had been raised under the influence of Electricity. The attention of the author was subsequently again called to this subject by the extraordinary effects reported to have resulted from the

application of Electricity to the soil, and from his having been solicited to take a part in the formation of an *Electro-cultural Society*; his experiments were repeated and varied in many ways, but with the same uniformly negative results as before. He feels bound to state his conviction, that we have no substantial grounds for believing that this agent, artificially supplied, has ever exercised the slightest influence in promoting vegetation, and that in some cases where it has been supposed to do so, other and unrecognized causes have concurred in bringing about the observed results.

(209) *Chemical effects.*—Dr. Priestley first investigated the chemical effects of ordinary Electricity, by passing a succession of shocks through a small quantity of water tinged blue by litmus: the liquid in a short time acquired a red tinge, while the air confined in the tube suffered evident diminution: an acid had been formed by the chemical union of the elements of atmospheric air, viz. oxygen and nitrogen. It was Mr. Cavendish, however, that first explained this experiment of Priestley. (See *Phil. Trans.* for 1784.)

(210) When a succession of discharges is sent through water, a decomposition of that fluid takes place, the elements of which assume the gaseous form. This fact was discovered in 1789, by Messrs Dieman, Paetz, and Van Troostwyck, associated with Mr. Cuthbertson. For the experiment they employed a glass tube a foot long, and one-eighth of an inch in diameter, through one end of which a gold wire was inserted, projecting about an inch and a half within the tube; that end was then hermetically sealed. Another wire was introduced at the other end of the tube, which was left open, and passed upwards, so that its extremity came to a distance of five-eighths of an inch from the end of the first wire. The tube was then filled with distilled water, from which the air had been extracted by the air-pump, and inverted in a vessel containing mercury. A little common air was let into the top of the tube, in order to prevent its being broken by the discharge. Electrical shocks were then passed between the two ends of the wires through the water in the tube by means of a Leyden jar, which had a square foot of coated surface. This jar was charged by a very powerful double plate machine, which caused it to discharge twenty-five times in fifteen revolutions. At each explosion bubbles of gas rose to the top of the tube; and when sufficient water had been displaced to lay bare the wires, the next shock kindled the gases and caused their re-union. Thus decomposition and recomposition were effected by the same agent. In the latter case, however, it may be supposed to have acted mechanically, or by the heat evolved in its passage through a badly conducting aëriform fluid.

(211) In 1801, Dr. Wollaston published in the Philosophical Transactions a description of a method of analyzing water by the transmission of sparks instead of shocks. He considered that the decomposition must depend upon duly proportioning the strength of the charge of Electricity to the quantity of water, and that the quantity exposed to its action at the surface of communication depends on the extent of that surface, he therefore expected that by reducing the surface of communication the decomposition might be effected by smaller machines and with less powerful excitation than were usually considered necessary for the purpose. "Having," he says, "procured a small wire of fine gold, and given to it as fine a point as I could, I inserted it into a capillary glass tube; and after heating the tube, so as to make it adhere to the point and cover it at every part, I gradually ground it down till with a pocket lens I could discern that the point of gold was disclosed. I coated several wires in this manner, and found that when sparks from a conductor were made to pass through water by means of a point so guarded, a spark passing to the distance of one-eighth of an inch would decompose water, when the point did not exceed $\frac{1}{700}$ of an inch in diameter. With another point, which I estimated at $\frac{1}{1500}$, a succession of sparks one-twentieth of an inch in length afforded a current of small bubbles of air."

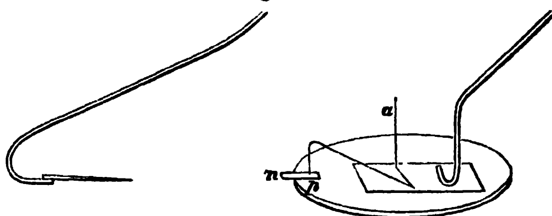
(212) In these ingenious experiments, however, true *electro-chemical* decomposition was not effected: that is, "the law which regulates the transference and final place of the evolved bodies had no influence." The water was decomposed at both poles independently of each other, and the oxygen and hydrogen gases evolved at the wires are the elements of the water existing the instant before in those places. "That the poles, or rather points, have no mutual decomposing dependence, may be shown," observes Faraday, "by substituting a wire, or the finger, for one of them,—a change which does not at all interfere with the other, though it stops all action at the charged pole. This fact may be observed by turning the machine for some time; for though bubbles will rise from the point left unaltered in quantity sufficient to cover entirely the wire used for the other communication, if they could be applied to it, yet not a single bubble will appear on that wire."

(213) The following beautiful experiments, made by Faraday (*Ex. Research.* series v. 462 *et seq.*), prove that, so far from electro-chemical decomposition depending upon the simultaneous action of *two metallic poles, air* itself may act as a pole, decomposition proceeding therewith as regularly and truly as with metal.

A piece of turmeric paper, not more than 0·4 of an inch in length,

and 0·3 of an inch in width, was moistened with sulphate of soda, and placed upon the edge of a glass plate opposite to and about two inches from a point connected with a discharging train arranged by connecting metallically a sufficiently thick wire with the metallic gas-pipes of the house, with those of the public gas-works of London, and with the metallic water-pipes of London. A piece of tin-foil resting upon the same glass-plate was connected with the machine and also with the turmeric paper by the decomposing wire *a*, Fig. 104. The

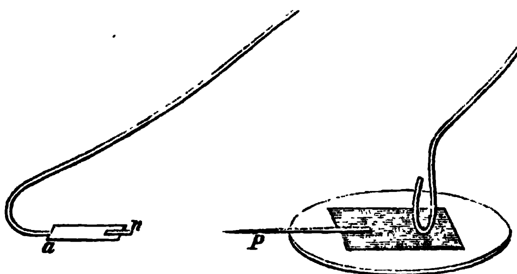
Fig. 104.



machine was then worked, the positive Electricity passing into the turmeric paper at the point *p*, and out at the extremity *n*. After forty or fifty turns of the machine (a plate fifty inches in diameter), the extremity *n* was examined, and the two points or angles found deeply coloured by the presence of free alkali.

A similar piece of litmus paper dipped in a solution of sulphate of soda (Fig. 105) was now supported upon the end of the discharging

Fig. 105.

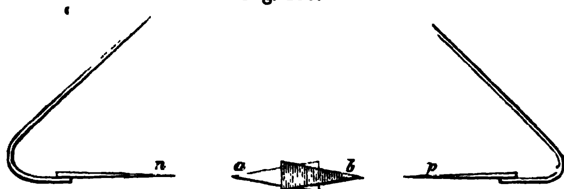


train *a*, and its extremity brought opposite to a point *p*, connected with the conductor of the machine. After working the machine for a short time, acid was developed at both corners towards the point, *i. e.* at both corners receiving the Electricity from the air. Then a long piece of turmeric paper, large at one end and pointed at the other, was moistened in the saline solution and immediately connected with the conductor of the machine, so that its pointed extremity was opposite a point upon the discharging train. When

the machine was worked, alkali was evolved at that point; and even when the discharging train was removed, and the Electricity left to be diffused and carried off altogether by the air, still alkali was evolved where the Electricity left the turmeric paper.

Arrangements were then made in which no metallic communication with the decomposing matter was allowed, but *both poles* formed of air only. Pieces of turmeric and litmus paper, *a b* (Fig. 106), moist-

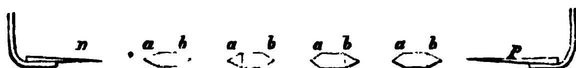
Fig. 106.



ened with solution of sulphate of soda, were supported on wax between the points, connected with the conductor of the machine and the discharging train, as shown in the figure; the interval between the respective points was about half an inch. On working the machine, evidence of decomposition soon appeared, the points *b* and *a* being reddened from the evolution of acid and alkali.

Lastly, four compound conductors of litmus and turmeric paper were arranged as shown in Fig. 107, being supported on glass rods;

Fig. 107.

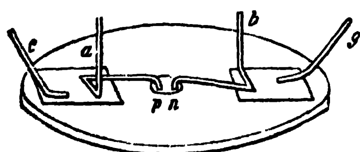


and on working the machine carefully, so as to avoid sparks and brushes, evidence of decomposition was obtained in each.

(214) Notwithstanding, then, the absence of metallic poles, we have here cases of electro-chemical decomposition precisely similar to those effected under the influence of the voltaic battery; and we appear to have direct proof also that the power which causes the separation of the elements is exerted not at the poles, but at the parts of the body which is suffering decomposition.

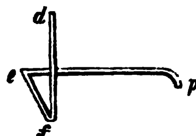
(215) The arrangement shown in Fig. 108 was employed by Faraday for effecting electro-chemical decomposition by common Electricity. On a glass plate, raised above a piece of white paper, two small slips of tin-foil, *a b*, were placed: one was connected by the insulated wire *c* with an electrical machine, and the other by the wire *g* with a

Fig. 108.



discharging train, or with the negative conductor. Two pieces of fine platinum wire, bent as in Fig. 109, were provided, and so arranged that the part *d f* was nearly upright, while the whole rested on the three bearing points *p e f*. The points *p n* thus became the decomposing poles. They were placed on a piece of filtering paper wetted with the solution to be experimented upon. When litmus paper, moistened in a solution of common salt or sulphate of soda, was employed, it was quickly reddened at *p*; a similar piece, moistened in muriatic acid, was very soon bleached at the same point, but no effects of a similar kind took place at *n*. A piece of turmeric paper, moistened in solution of sulphate of soda, was reddened at *n* by two or three turns of the machine; and in twenty or thirty turns, plenty of *alkali* was there evolved. On turning the paper round, so that the spot came under *p*, and then working the machine, the alkali soon disappeared, the place became yellow, and a brown alkaline spot appeared in the new part under *n*. When pieces of litmus paper and turmeric paper, both wetted with solution of sulphate of soda, were combined, and put upon the glass, so that *p* was on the litmus, and *n* on the turmeric, a very few turns of the machine sufficed to show the evolution of acid at the former and alkali at the latter, exactly in the manner effected by a volta-electric current. (See *Ex. Researches*, third series, 309 *et seq.*)

Fig. 109.



(216) In these experiments the direct passage of sparks must be carefully avoided. If sparks be passed over moistened litmus paper, it is reddened; and if over paper moistened with solution of iodide of potassium, iodine is evolved. But these effects must carefully be distinguished from those due to electro-chemical powers, or true *electrolytic* action, and must be carefully avoided when the latter are sought for. The effect just mentioned is occasioned by the formation of nitric acid by the chemical union of the oxygen and the nitrogen of the air: the acid so formed, though very small in quantity, is in a high state of concentration, and therefore reddens the litmus paper, and decomposes the iodide.

(217) It does not appear that Faraday was more successful than Wollaston in effecting a true electro-polar decomposition of water. He says (329), "there is reason to believe that when electro-chemical decomposition takes place, the quantity of matter decomposed is not proportionate to the intensity, but to the quantity of Electricity passed; but in Wollaston's experiment this is not the case. If, with a constant pair of points the Electricity be passed from the machine in sparks, a certain proportion of gas is evolved; but if the sparks be

rendered shorter, less gas is evolved; and if no sparks be passed, there is scarcely a sensible portion of gases set free. On substituting solution of sulphate of soda for water, scarcely a sensible quantity of gas could be procured, even with powerful sparks, and almost none with the mere current; yet the quantity of Electricity in a given time was the same in all these cases." "I believe at present that common Electricity can decompose water in a manner analogous to that of the voltaic pile. But when I consider the *true effect* only was obtained, the quantity of gas given off was so small, that I could not ascertain whether it was, as it ought to be, oxygen at one wire and hydrogen at the other. On substituting solution of sulphate of soda for pure water, these minute streams were still observed; but the quantities were so small, that on working the machine for half an hour, I could not obtain at either pole a bubble of gas larger than a small grain of sand; and if the chemical power be in direct proportion to the absolute quantity of Electricity which passes, this ought to be the case." In paragraph 359 he says, "It is doubtful whether any common electrical machine has yet been able to supply Electricity sufficient in a reasonable time to cause true electro-chemical decomposition of water."

(218) Mr. Goodman, of Salford, near Manchester, who published some years ago a very ingenious essay on the "Modifications of the Electric Fluid," has succeeded in decomposing water *by current alone*, and with *unguarded poles*: he states that the experiment is most readily performed by exposing $\frac{1}{16}$ of an inch of the ends of two fine platina wires, immersed in distilled water. The extremities thus exposed are after a few turns of the machine (which must be a powerful one), covered over with gas bubbles, producing a *frosted* appearance, and at all times in double quantity on the *negative* or *hydrogen* pole. The gas may speedily, and sometimes from the outset also, be seen to ascend, especially with a small convex lens.

(219) Mr. Goodman has described a method of polarizing frictional Electricity by arranging a series of circular glass plates on an insulating axis, and applying to each two metallic moveable coatings. The first coating is placed by means of a wire, in connexion with the positive conductor of an electrical machine, its outer surface and coating being in communication with the inner surface of the next plate, and so on throughout the series: the last surface being connected with the negative conductor of the machine. The physiological effect of this arrangement is described as being entirely novel, the sensations produced by the electro-magnetic machine being exactly imitated; but Mr. Goodman did not succeed in effecting the polar decomposition of water by it, the gas generated being a mixture of oxygen and hydrogen at each pole: but when the Electricity was

collected by means of points, in connexion with each individual surface, the occurrence of shocks in the current was prevented, and the gas was obtained in a manner perfectly identical with galvanic decomposition, though in quantity so minute that, after nearly two hours' turning, only a small bubble of about one eighth of an inch in length was obtained.

(220) In order to obtain as complete a proof as possible of the identity of the galvanic and ordinary Electricities, Mr. Goodman endeavoured so to unite them, that they should act in concert in the decomposition of water: with this view he arranged two wine-glasses of distilled water, and inserted in each two guarded poles,* one of which was from a *couronne des tasses* of ten or twelve jars, and the other (the opposite pole) from the electrical machine: thus there was a positive pole from the machine, and a negative pole from the battery in one glass; and a negative pole from the machine, and a positive pole from the battery in the other glass. The experiment succeeded, and gas was generated by each of the four poles. It was afterwards found that a similar effect might take place with the frictional fluid alone.

(221) In order to obviate that objection to "guarded points," before alluded to, viz., that they have no "mutual decomposing dependence," Mr. Goodman determined to attempt decomposition by *unguarded* ones. Having at hand two hammered platina wires, without any glass or other coating upon them, the point of one was slowly passed beneath the surface of the water, and when about one-eighth of an inch immersed, it became speedily covered with minute bubbles: the decomposition proceeding as usual at the guarded pole during the whole period. The guarded pole was then removed, and the second unguarded one substituted, and on turning the machine for a very short period, both poles were entirely covered with gas, the *negative* in about *twofold* quantity: thus, decomposition of water was effected perfectly identical with galvanism, from the prime conductor of the machine alone, and subject to no objections on the ground of the metal poles being covered with non-conducting matter.

* The guarded poles were thus constructed:—a piece of the finest platinum wire was hammered at its extremity, until it formed a flat plate, whose area was about ten or twelve times the diameter of the wire: then, with a pair of scissors it was cut into as fine a point and filament as possible, placed in a small glass tube, the extremity of which was melted until it adhered to and covered the filament, and afterwards by grinding a point, was exposed sufficiently for a small spark from the machine just to pass,—which point could not be discovered either with the naked eye or a miscroscope.

(222) Two guarded poles were next immersed in separate glasses of water, one being connected with the outer, and the other with the inner coating of a charged and insulated Leyden phial: the object being to see whether oxygen and hydrogen would be eliminated in *each* vessel, *independently* of the other. Upon attempting to pass shocks, however, no trace of gas could be observed; but when a communication was established between the glasses, by means of a bent copper wire, decomposition instantly proceeded, visibly at the guarded poles: a piece of copper wire was then inserted in a glass of distilled water, in which a guarded pole was placed, and after about twenty minutes' turning, it became covered with bubbles of gas. Three glasses were then arranged: in the two outer, guarded poles were placed, connected respectively with the positive and negative conductors of the electrical machine, and each was then connected with the middle glass by a bent platina wire, the ends of which dipped about an eighth of an inch below the surface of the water. In five minutes, bubbles of gas made their appearance on the inserted termination of *each* wire, and in twenty minutes very considerable bubbles were found, as *distinct as in any* galvanic decomposition, and commenced ascending from the surface of the wires.

(223) The currents were next introduced into the glasses, without any guarded pole whatever, copper wires being substituted: in *two minutes and a half* gas was evident upon every termination: and, lastly, two thick unguarded wires were inserted in a *single* wine-glass, one wire proceeding from the positive, and the other from the negative conductor,—in *three minutes* bubbles appeared: in *five minutes*, all parts of the wires below the water assumed a frosted appearance, about double the quantity of bubbles appearing on the negative wire, and in half an hour, the covering, especially of the negative pole, might be seen at the distance of two yards, exhibiting as fair an electro-chemical effect as is ever observed in voltaic Electricity.

(224) Mr. Goodman having kindly furnished the author with a pair of the guarded points, employed in his own experiments, he has much pleasure in stating that he has tried them with very satisfactory results. Five turns of a two feet plate machine, in good action, were sufficient to produce a bubble of gas on the negative point,— twenty turns gave bubbles on both: that on the negative wire being, as nearly as the eye could judge, double the size of that on the positive, and 100 turns sent the gas from the negative point in a shower of minute bubbles, while the bubble on the positive point became as big as the head of a large pin. There is no doubt, that in this experiment, the decomposition was *true electro-polar*, although there is no direct proof that such is really the case.

CHAPTER VI.

ATMOSPHERIC ELECTRICITY.

Exploring wires—Electrical kites—Electrical observations at the observatories of Kew and Brussels—Lightning and thunder—Lightning conductors—Tornadoes and waterspouts—The aurora borealis—Induction of atmospheric Electricity in the wires of the electric telegraph—Analogy of the submerged electric telegraph wire to the Leyden phial.

(225) THE atmosphere is that part of our planet in which the Electricity liberated by various processes accumulates; it is the great natural reservoir of sensible Electricity which is found there in different degrees of intensity, varying also in its condition, being sometimes positive and at other times negative. When the air is clear and the sky serene, the Electricity is generally positive; in damp or rainy weather it is more frequently negative. In the higher regions it is more powerful than in the lower; it is also stronger in winter than in summer; and when the air is still than during the prevalence of wind. The transitions in the electrical state of the atmosphere from positive to negative, were frequently observed by Humboldt during his travels in the equinoctial regions of the new continent. "I saw here,"* he writes (*Travels*, vol. ii. p. 143), "what I had often observed in the ridge of the Andes during a storm, that the Electricity of the atmosphere was first positive, then *nil*, then negative. These oscillations from positive to negative were frequently repeated; yet the Electrometer constantly denoted a little before the lightning only E or + E and never —E . . . . We noticed in the valleys of Aragua the increase of atmospheric Electricity with the augmentation of vesicular vapours, and the Electrometer of Volta constantly displayed at sunset positive Electricity. During whole hours in the day-time the Electricity was *nil*, then it would become very strong, and soon after again imperceptible."

(226) It has been ascertained by the observations of De Saussure, Schubler, Arago, and others, that the positive Electricity of the atmosphere is subject to diurnal variations of intensity, there being two *maxima* and two *minima* every twenty-four hours. The first

* On the banks of the river Apure.

minimum takes place a little before the rising of the sun; as it rises, the intensity at first gradually, and then rapidly increases, and arrives at its first *maximum* a few hours after. This excess diminishes at first rapidly and afterwards slowly, and arrives at its *minimum* some hours before sunset. It re-ascends when the sun approaches the horizon, and attains its second *maximum* a few hours after, then diminishes till sun-rise, and proceeds in the order already indicated.

The *intensity* of the free Electricity of the atmosphere has also been found to undergo annual changes, increasing from the month of July to the month of November, inclusive; so that the greatest intensity occurs in winter and the least in summer. In cloudy weather the free Electricity of the air is still *positive*. During storms, or when it rains or snows, it is sometimes *positive* and sometimes *negative*, and its intensity is always more considerable than in serene weather. During a storm, the Electroscope will frequently indicate several changes, from *positive* to *negative*.

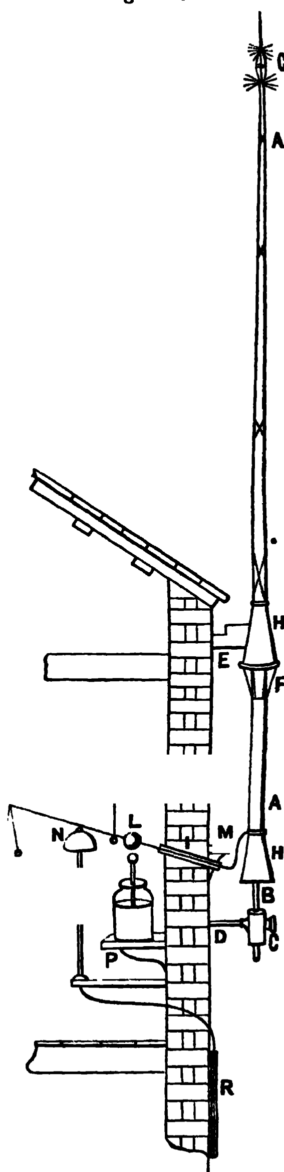
The Electricity of the atmosphere, whether we consider it in reference to ourselves as being continually exposed to its quiet, as well as to its disturbed influence, or to the grandeur and magnificence of the phenomena which it displays, is perhaps the most interesting branch of this captivating science.

(227) The Electricity of the atmosphere is examined by means of exploring conductors, exploring wires, and kites. The collector employed by Cavallo was simply a common jointed fishing rod, the smallest joint of which was re-placed by a well varnished and slender glass tube surmounted by a cork, from which was suspended a pith-ball Electroscope, which could be insulated and uninsulated at pleasure by means of a pin and piece of string. When an observation was to be made, the rod was held out of one of the highest windows of a house, at an angle of about 50° or 60°, and kept there for a few minutes, the Electroscope being uninsulated; the balls were then insulated by removing the pin by pulling the cord; and the balls then became electrified in a state opposite to that of the atmosphere.

(228) Read, who made many experiments on the Electricity of the atmosphere, employed the conductor, or "thunder rod," shown in Fig. 110. (*Encycl. Brit.*) It consisted of a wooden rod, A A, twenty feet long, one inch in diameter at the top and two at the bottom. Into the lower end was cemented a solid glass pillar B, coated with wax, and twenty-two inches long. This pillar rested on a wooden pedestal C, carried by a bracket D. At thirteen inches above D, the rod passes through a stout glass tube, F, coated with wax, and supported by a strong arm of wood E. A lining of cork lies between the rod A and the tube F, to prevent the latter from

being broken when the rod is bent by the wind. Several sharp pointed copper wires, G, stand out from the top of the tube. The use of the funnels, H H, is to defend the glass rods, B F, from the weather. Through a hole in the wall at I, passes a glass tube, coated with sealing-wax, through which a strong brass wire passes from the rod at M into the room. At the end of the tube this wire passes through a brass ball, L, two inches in diameter; and after proceeding a little further, it suspends from its extremity a pith-ball electrometer, K, about twelve inches from the wall. A bell, N, carried by a strong wire, is placed two inches from the brass ball, L, three-tenths of an inch in diameter, suspended from the nail, O. The bell N, which has a metallic communication R, with the moist ground, is rung by the ball L. Jars and other pieces of apparatus are placed, when wanted, upon the small shelf P, and all this part of the apparatus is protected from the weather by being enclosed in a wooden box.

Fig. 110.

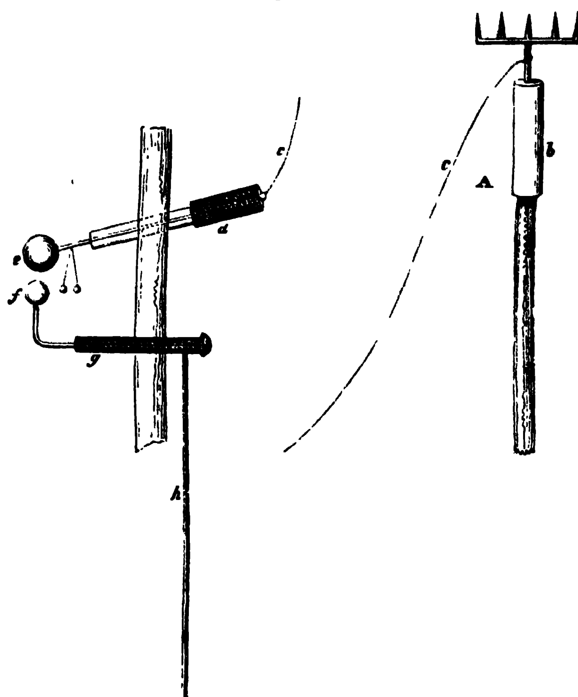


(229) The simple exploring apparatus shown in Fig. 111, was erected by the author some years ago, and though the situation was low, it frequently afforded highly interesting exhibitions of electrical phenomena. During hail-storms large Leyden jars were repeatedly charged from the ball *e*, and every electrical cloud that passed over the factory indicated its vicinity either by the passage of small sparks between the balls *e* and *f*, or by the divergence of the pith balls.

A represents the top of a tall fir-pole, thirty-five feet in height, fixed on the chimney of a factory; *b*, a painted copper funnel, surmounted with a brass four-pronged fork, from which the copper wire

c proceeds, and is conducted to a second insulated funnel *d*, enclosing a thick brass wire, which, insulated by a stout glass tube, passes

Fig. 111.



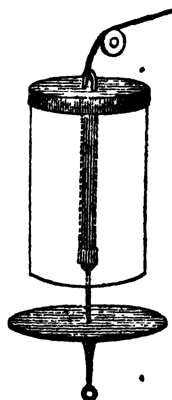
through the stone-work of the laboratory window, and terminates in a two-inch brass ball *e*; *f* is a smaller ball connected with a bent wire passing into the gun-barrel *g*, and capable of being brought to any required distance from the ball *e*; the gun-barrel passes through the stone-work of the window, and is metallically connected with the earth by the iron rod *h*. There is also an arrangement not shown in the figure, consisting of a stout iron rod capped with a brass ball fixed at about two inches distant from the funnel *d*; this rod passes into the earth, and thus prevents any accident which might arise from a flash of lightning striking the apparatus. The fir-pole A is terminated by a stout glass rod eighteen inches long, to which the funnel serves as a protection. A pair of small pith-balls are suspended from the ball *e*, which by their divergence give notice of the electrical state of the apparatus.

An instrument for investigating the electric state of the atmosphere was constructed by M. Colladon, of Geneva, on the following

principle. He found that if the two ends of the wire of a galvanic multiplier, consisting of very numerous coils well insulated from each other, were brought in contact, one with a body positively, and the other with a body negatively charged, a current of Electricity passes through the wire until equilibrium is restored, the energy and direction of this current is indicated by the deviation of the needle from the zero point of the scale. This instrument is applied to the purpose of ascertaining and measuring the atmospheric Electricity by communicating one end of the wire with the earth, and allowing the other to extend into the region of the atmosphere, the electrical state of which is intended to be compared.

(230) Mr. Crosse collects the Electricity of the atmosphere by means of wires supported and insulated on poles fixed on some of the tallest of the magnificent trees which ornament his grounds. As far as the eye can reach, these poles may be seen, though when the author visited Broomfield in 1844, in consequence of some extensive damages which happened during a violent storm, not more than 1600 feet of wire were insulated. The wires are insulated on the poles by means of funnels, one of which is represented in Fig. 112. It is made of copper, about four and a half inches in diameter, and eleven inches in length, and into a cavity or socket of about two inches deep formed at the closed end of the funnel, is firmly cemented a stout glass rod of sufficient length to reach to the open end of the funnel, where it is mounted, by means of strong cement, with a metallic cap and staple. The latter appendage receives the hook of a very strong wire, which passes through a circular plate of copper placed about four inches from the mouth of the funnel, and terminates in a hook to which one end of the exploring wire is fixed. The object of the metallic disc is to preclude the admission of snow, rain, &c., and thus to preserve the glass rod in a dry insulating condition. These funnels are easily raised to the tops of the poles by an arrangement of pulleys, and thus the wires can at pleasure be drawn up and taken down. Outside the window of the gallery of the electrical room is fixed firmly in the ground a stout pole, on the top of which a large insulated funnel is fixed, and this forms the termination of the exploring wire, the Electricity being conveyed from it through the window by means of a stout wire to a large brass ball, from which again it is conveyed by a curved wire to a brass conductor insulated and fixed on a table, and bearing the appropriate words, "*Noli me*

Fig. 112.



tangere." On the same plane with the conductor is fixed another arrangement having a metallic communication with a neighbouring pond, and by means of a screw the brass ball with which it is terminated may be adjusted at any required distance from the opposed brass ball of the conductor. Another most important piece of apparatus is a lever furnished with an insulating handle, by means of which the current of Electricity, when too strong, or when no experiments are in progress, is easily directed into the earth outside the window, and without entering the room.

(231) The electrical battery employed by Mr. Crosse consists of fifty jars, containing seventy-three square feet of coated surface: to charge it requires two hundred and thirty vigorous turns of the wheel of a twenty-inch cylinder electrical machine: nevertheless, with about one-third of a mile of wire, Mr. Crosse has frequently collected sufficient Electricity to charge and discharge this battery twenty times in a minute, accompanied by reports as loud as those of a cannon. The battery is charged through the medium of a large brass ball, suspended from the ceiling immediately over it, and connected, by means of a long wire, with the conductor in the gallery: this ball is raised from, and let down to, the battery by means of a long silk cord, passing over a pulley in the ceiling: and thus this extraordinary electrician, while sitting calmly at his study table, views with philosophic satisfaction the wonderful powers of this fearful agent, over which he possesses entire control, directing it at his will; and, with a simple motion of his hand, banishing it instantaneously from his presence.

(232) The following account of the construction of a thunder cloud, as examined by means of the exploring wires, has been kindly furnished for this work by Mr. Crosse:—

"On the approach of a thunder cloud to the insulated atmospheric wire, the conductor attached to it, which is screwed into a table in my electrical room, gives corresponding signs of electrical action. In fair cloudy weather the atmospheric Electricity is invariably positive, increasing in intensity at sun-rise and sun-set, and diminishing at midday and midnight, varying as the evaporation of the moisture in the air: but when the thunder cloud (which appears to be formed by an unusually powerful evaporation, arising either from a scorching sun succeeding much wet, or *vice versâ*) draws near, the pith-balls suspended from the conductor open wide, with either positive or negative Electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size, carefully connected with the nearest spot of moist ground. I

usually connect a large jar with the conductor, which increases the force of, and in some degree regulates the number of the explosions; and the two balls between which the discharges pass can be easily regulated, as to their distance from each other, by a screw. After a certain number of explosions, say of negative Electricity, which at first may be nine or ten in a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of positive Electricity takes place, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of the cloud:* then follows a second zone of negative Electricity, occasioning several more discharges in a minute than from either of the first pair of zones; which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of positive Electricity, indicating the passage of a second pair of zones: these, in like manner, are followed by others, fearfully increasing the rapidity of the discharges, when a *regular stream commences,* interrupted only by the change into the opposite Electricities. The intensity of each new pair of zones is greater than that of the former, as may be proved by removing the two balls to a greater distance from each other. When the centre of the cloud is vertical to the wire, the greatest effect consequently takes place, during which the *windows rattle in their frames,* and the bursts of thunder without, and noise within, every now and then accompanied with a crash of accumulated fluid in the wire, striving to get free between the balls, produce the most awful effect, which is not a little increased by the pauses occasioned by the interchange of zones. Great caution must, of course, be observed during this interval, or the consequences would be fatal. My battery consists of fifty jars, containing seventy-three feet of surface, on *one side* only. This battery, when fully charged, will perfectly fuse into red-hot balls thirty feet of iron wire, in one length, such wire being $\frac{1}{210}$ of an inch in diameter. When this battery is connected with three thousand feet of exploring wire, during a thunder storm, it is charged fully and instantaneously, and of course as quickly discharged. As I am fearful of destroying my jars, I connect the two opposite coatings of the battery with brass balls, one inch in diameter, and placed at such distance from each other as to cause a discharge when the battery receives three-fourths of its charge. When the middle of a thunder-cloud is over head, a crashing stream of discharges takes place between the balls, the effect of which must be witnessed to be conceived.

"As the cloud passes onward, the opposite portions of the zones, which first affected the wire, come into play, and the effect is

weakened with each successive pair till all dies away, and not enough Electricity remains in the atmosphere to affect a gold-leaf Electrometer. I have remarked that the air is remarkably free of Electricity, at least more so than usual, both before and after the passage of one of these clouds. Sometimes, a little previous to a storm, the gold leaves connected with the conductor will for many hours open and shut rapidly, as if they were panting, evidently showing a great electrical disturbance.

"It is known to electricians, that if an insulated plate, composed of a perfect or an imperfect conductor, be electrified, the Electricity communicated will radiate from the centre to the circumference, *increasing* in force as the squares of the distances from the centre; whereas in a thunder-cloud the reverse takes place, as its power *diminishes* from the centre to the circumference. First a nucleus appears to be formed, say of positive Electricity, embracing a large portion of the centre of the cloud, round which is a negative zone of equal power with the former; then follow the other zones in pairs, diminishing in power to the edge of the cloud. *Directly below this cloud*, according to the laws of inductive Electricity, must exist on the surface of the earth a nucleus, of opposite or negative Electricity, with its corresponding zone of positive, and with other zones of electrified surface, corresponding in number to those of the cloud above, although each is oppositely electrified. A discharge of the positive nucleus above into that of the negative below, is commonly that which occurs when a flash of lightning is seen; or from the positive below to the negative above, as the case may be: and this discharge may take place according to the laws of Electricity, through any or all of the surrounding zones, *without influencing their respective Electricities* otherwise than by weakening their force, by the removal of a portion of the electric fluid from the central nucleus above to that below: every successive flash, from the cloud to the earth, or from the earth to the cloud, weakening the charge of the plate of air, of which the cloud and the earth form the two opposite coatings. Much might be said upon this head, of which the above is but a slight sketch."

At a later date, Mr. Crosse adds: "At the time I made these experiments on the Electricity of the atmosphere, I was much puzzled to account for the separation of the cloud into concentric and opposite electrical zones. I was at first inclined to refer this phenomenon to the fact of the cloud being a *secondary* conductor; and in consequence I insulated and electrified various plates of a secondary conducting power, such as moist wood, leather, &c., &c., and compared the Electricity which resided on every part of their

surfaces with that which was communicated to insulated *primary* conductors, and I found no difference in the residence of the electric fluid, as in both primary and secondary conductors it radiated equally from the centre to the circumference; nor was the least symptom of an oppositely electrified zone discoverable. At last I hit upon what I believe to be the *real cause* of the phenomena. A cloud is of course a mass of vapour of a *secondary* conducting nature; but that is not sufficient to account for the zones. A cloud is composed of minute particles of water, each separated from its neighbour, and held in suspension by the caloric, which causes it to be elevated into the atmosphere in the form of vapour; consequently the whole cloud is *subdivided* into little conducting spheres, and resembles in this respect a dry plate of glass gently breathed upon, or a plate of glass dotted all over with spots of tin-foil. If you form a plate of this nature, and electrify the central spot with a spark from a charged jar, what is the consequence? Why the communicated Electricity will strike from the central spot across the contiguous spaces, and divide its Electricity equally amongst them, and in a circle; and when it has exhausted its *communicating* power, an *inductive influence* begins, which in its turn communicates the opposite Electricity to the neighbouring spots, in a concentric circle, around the first nucleus formed. Here we have one pair of zones, which will in like manner be followed by a second pair, and so on, till the whole cloud is arranged accordingly; the central zones being the most powerfully electrified, and those at the circumference the weakest. By reasoning analogically it *must* be so. The more powerfully electrified is the cloud, the wider and more extensive is each pair of zones, and also the more numerous. Should I be asked, *what* influence is it that first impresses this electric power on the centre of the thunder cloud?—I could not presume to answer. Rudely speaking, evaporation seems to be the main cause. I should, in speaking of the conducting nature of clouds and vapours, make use of a new term, and call them *disseminated* conductors, in opposition to those of an uniform substance. It is the *interval*, the *non-conducting* interval between each particle of suspended water, which is the cause of these effects; it being a law of Electricity that a number of small intervals between conducting substances impede the communicating power as much as *one greater interval*, and hence the inductive power."

(233) Magnificent and astounding as must have been such a spectacle as that above so forcibly described, it was if possible exceeded in brilliancy by the electrical phenomena observed some years since by Mr. Crosse, during a dense November fog, of which he has

favoured us with the following interesting account:—"Many years since, I was sitting in my electrical room on a dark November day, during a very dense driving fog and rain which had prevailed for many hours, sweeping over the earth, impelled by a south-west wind. The mercury in the barometer was low, and the thermometer indicated a low temperature. I had at this time 1,600 feet of wire insulated, which, crossing two small valleys, brought the electric fluid into my room. There were four insulators, and each of them was streaming with wet, from the effects of the driving fog. From about eight o'clock in the morning until four in the afternoon, not the least appearance of Electricity was visible at the atmospheric conductor, even by the most careful application of the condenser and multiplier; indeed, so effectually did the exploring wire conduct away the Electricity which was communicated to it, that when it was connected by means of a copper wire with the prime conductor of my 18-inch cylinder in high action, and a gold leaf Electrometer placed in contact with the connecting wire, not the slightest effect was produced upon the gold leaves. Having given up the trial of further experiments upon it, I took a book, and occupied myself with reading, leaving by chance the receiving ball at upwards of an inch distance from the ball in the atmospheric conductor. About four o'clock in the afternoon, whilst I was still reading, I suddenly heard a very strong explosion between the two balls, and shortly after many more took place, until they became one uninterrupted stream of explosions, which died away and re-commenced with the opposite Electricity in equal violence. The stream of fire was too vivid to look at for any length of time, and the effect was most splendid, and continued without intermission, save that occasioned by the interchange of Electricities, *for upwards of five hours*, and then ceased totally. During the whole day, and a great part of the succeeding night, there was no material change in the barometer, thermometer, hygrometer, or wind; nor did the driving fog and rain alter in its violence. The wind was not high, but blew steadily from the S.W. Had it not been for my exploring wire, I should not have had the least idea of such an electrical accumulation in the atmosphere: the least contact with the conductor would have *occasioned instant death*,—the stream of fluid far exceeding any thing I ever witnessed, excepting during a thunderstorm. *Had the insulators been dry, what would have been the effect?* In every acre of fog, there was enough of accumulated Electricity to have destroyed every animal within that acre. How can this be accounted for? How much have we to learn before we can boast of understanding this intricate science?"

(234) Amongst those individuals in whom the splendid electrical

achievements of Mr. Crosse excited an ardent taste for atmospheric investigations, the late Mr. Weekes, of Sandwich, must not be allowed to pass unnoticed. This gentleman, at considerable trouble and expense, erected an exploring wire, about 365 yards horizontally over the town in which he resided, insulating it against the balls from which arise the vane-spindles of the two churches, and conducting the termination to an insulated arrangement in his laboratory. "The scenes enacted by this apparatus," to use the Sandwich electrician's own language, "are occasionally distinguished by a magnificence and interest which nothing short of ocular demonstration can serve to portray; nor, perhaps, are the almost hourly varying phenomena of its minor indications less deserving attention from the inquisitive admirer of natural science. When the gathering storm-cloud, pregnant with infuriated lightnings, and momentarily gaining additional sublimity from reverberating peals of deafening thunder, lingers over the line of wire, and deluges the earth with rain, or batters its beautiful foliage with unrelenting showers of hail,—then, tremendous torrents of electric matter, assuming the form of dense sparks, and possessing most astonishing intensity, rush from the terminus of the instrument with loud cracking reports, resembling in general effect the well-known running fire occasioned by the vehement discharge of a multiplicity of small fire-arms. Fluids are rapidly decomposed: metals are brilliantly deflagrated; and large extents of coated surface repeatedly charged and discharged in the space of a few seconds. When these phenomena occur incidental to the hours of darkness, the lightning flash is seen harmlessly to play in various zig-zag and fantastic shapes amidst the several contrivances by means of which its power is subdued; thus augmenting the sublimity of a scene, compared to the correct delineation of which the efforts of language are but imbecility. Again, relinquishing its claims to the terrific and sublime for features of a more gentle complexion, even the light and feathery aggregations of the summer cloud are found capable of imparting to a pair of delicate gold-leaf pendulums, a test by which the philosopher assigns a character to inaccessible regions of the atmosphere."

(235) In the sixth volume of "Sturgeon's Annals of Electricity," Mr. Weekes has given a most interesting description of some brilliant electrical phenomena observed during a grand hail-storm which occurred at Sandwich on the 9th of May, 1841; but as it would be impossible to do justice to the account without the plate which accompanies it, and which is somewhat too large to be inserted here, we must be satisfied with referring our readers to the original paper. In the same volume, page 98, will be found another equally interest-

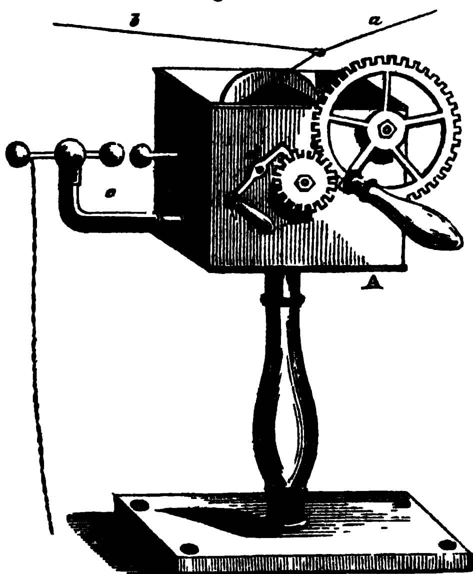
ing communication from Mr. Weekes, in which he describes some electrical phenomena observed by him during a thunder-storm in the autumn of 1840, particularly the alternation of the Electricity from positive to negative, indicating the passage of zones, and verifying Mr. Crosse's idea of the construction of a thunder-cloud. This same paper contains an account of some experiments made by the author with a view of insulating *ozone*, the name given by M. Schoenbein to that peculiar odorous principle which appears to be developed when ordinary Electricity passes from the points of a conductor to the surrounding air, and which is also disengaged whilst water is decomposing by a voltaic current. It is the opinion of M. Schoenbein that this odorous principle should be classed in that genera of bodies to which chlorine and bromine apparently belong; that it is always disengaged in the air in sufficiently notable quantities during stormy weather; and he suggests the following method of rendering it evident, founded on its property of rendering gold and platinum electro-negative; viz. to place plates of platinum in situations sufficiently elevated, taking care that they communicate with the earth: as soon as these plates become negatively polar, M. Schoenbein thinks that it may be concluded that ozone is developed.

(236) Mr. Weekes found that when a piece of platinum foil three or four inches square, fastened to a wire, and held in the hand of the operator, was brought for a few seconds into the vicinity of the terminal ball of his aërial apparatus, when a free current in the form of sparks was passing, the plate acquired a negative polarity, which may be immediately shown by the galvanometer, and the experiment repeated with the greatest facility as often as desired. He constructed an apparatus by which dense sparks of Electricity were caused to pass for about fifteen seconds between two metallic plates enclosed in a cylinder of glass: and he states, that on removing the cover of the arrangement the atmosphere of the cylinder had become so strongly impregnated with a powerful pungent phosphoric odour, that he found it exceedingly inconvenient to respire over it; nor could he find any individual willing to permit its approach towards his nostrils beyond a second or two. Several highly interesting facts connected with this peculiar odorous principle have been collected; and in a future chapter we shall take occasion to advert to them.

(237) By means of exploring rods and wires, the Electricity of the *lower* atmosphere may be easily collected and examined, but for bringing it down from the higher regions the grand Franklinian kite experiment must be resorted to (17). The experiments with the electrical kite are very interesting, but great caution is required, and poor Richman's untimely end (19) should be steadily before the

mind while conducting them. When thunder-clouds are about, the string should never be allowed to pass through the hand while raising the kite, even though it have a good connexion with the ground: indeed, even under a cloudless sky, during a smart north-east breeze, we have frequently experienced very unpleasant shocks whilst letting out the string. By employing, however, the little apparatus shown in Fig. 113, complete security is insured, and we strongly recommend it to the notice of kite experimenters. A is a square copper box supported on a stout glass pillar (not less than two inches thick), and firmly cemented into a baseboard, which is secured to the ground by strong iron pegs nine inches long, passing through the holes and driven into the ground. The box contains a reel round which the wired string is wound: it is turned by a glass handle fixed on the multiplying wheel. *d* is a small catch moved by a key furnished with a glass handle, by which the reel may be stopped when required without touching the string. *c* is a Lane's electrometer provided with a screw adjustment, by which the distance between the brass balls may be regulated with the greatest nicety; it is connected with the ground by a chain or wire. The method of using this apparatus will immediately be understood. When the kite (which may be simply a silk-handkerchief, stretched on a cross of light wood) is raised a sufficient height from the ground for the wind to act upon it, the string need no longer be held in the hand, the kite draws it from the reel, and the experimenter, by means of the catch and key, has it under his complete control. When a sufficient quantity of string has been taken out, a silk cord, two or three yards long, is thrown over the string, and, by means of a running noose, tightened upon it, and the other end made fast to a post; by this means the strain is taken off the box. On ordinary occasions, that is, when no unusual exhibitions of Electricity are

Fig. 113.



anticipated, the balls of the discharger may be set about one-fifth of an inch apart, and, instead of connecting the sliding wire with the earth, it may be put in communication with the interior coating of a Leyden phial. In a few minutes, sparks pass between the balls, and on fine dry days, when the wind is in the north, or north-east, with about half a mile of wired string out, we have frequently had discharges at the rate of one a minute from the jar, through a striking distance of one-fourth of an inch, for hours together. In order to test the species of Electricity collected, the jar is discharged through a helix of copper-wire, enclosing a needle: after five or six explosions have passed, the needle becomes magnetized, the direction of the poles indicating the manner in which the jar was charged. If the helix be a *right handed* one, that is, one in which the convolutions take the same direction as that in which the hands of a watch move, then, if the jar be charged *positively*, that extremity of the needle lying in the coil, which is nearest the *negative* or outside coating of the jar, will become a north pole. If the helix be left-handed, the results are exactly the reverse.

(238) It is most interesting to watch the effect of clouds passing near the kite, their presence being invariably indicated by the increased rapidity of the discharges between the balls: the distance at which the Electricity is communicated is indeed astonishing. We have frequently observed a very marked alteration in the discharges from the approach of a single and small cloud before it could have reached within half a mile of the kite, and we have often astonished by-standers who have been amusing themselves by drawing small sparks from the string with their knuckles, by watching the opportunity presented by the approach of one of these clouds, and then desiring them to repeat their experiment, and the result has generally been a shock, which has taught them to treat the apparatus with far greater respect than before.

(239) One of the first things that the kite experimenter will probably notice, is the peculiar pungency of the spark: we are accustomed to receive sparks an inch long from the prime conductor of an electrical machine, for amusement; it would not, however, be safe to approach a kite-string from which sparks of such a length might be drawn. The shock from sparks half an inch long are generally very severe, and resembling more the shock from a highly charged small Leyden phial, than that from the prime conductor: the length of the spark is not, however, altogether the criterion of the intensity of the Electricity, which depends upon the quantity of string extended, and more still upon the state of the atmosphere.

(240) It is sometimes necessary to penetrate regions of the

atmosphere beyond the height attainable by a single kite, before signs of Electricity can be obtained; this may be done by letting two, three, or more kites fly from the same string. The first kite is sent up as usual, and when it has reached its maximum elevation, the end of its string is put through a slit in the middle stick of the second, and tied to its string: the second kite is then raised, in like manner a third may be added, and thus great heights may be reached provided the wind is blowing in the same direction at all altitudes. Mr. Cuthbertson (*Practical Electricity*) relates the following experiment where three kites were employed. "Some years ago, in the month of May, I let a kite fly with 500 feet of cord, which seemed to be as great a weight as it could carry, but as no sparks could be got from the wire in the string, and the kite would not rise higher, I fastened a second to it, and they both continued rising, till the second had 500 feet more cord, but still it showed only faint signs of Electricity. A third kite was then added, which took 500 feet more, and then sparks were drawn, but very weak, only just felt in the finger. The wind was south-west, and the sky covered with clouds. I had observed, that in such a state of the atmosphere, little or no Electricity could be obtained, and that the Electricity was the strongest when there were no clouds, or very few, excepting in thunderstorms. I often repeated such experiments at that time, and always found the Electricity from the kites to be *positive*, but other writers make mention of having had both *positive* and *negative*."

(241) Mr. Sturgeon's kite experiments appear to have been very extensive. "I have made," says he, "upwards of five hundred electric kite experiments, under almost every circumstance of weather, at various times of the day and night, and in every season of the year; I have experimented on Shooter's Hill, and on the low lands on the Woolwich and Welling sides of it, and the experiments in the three different places within an hour of each other; I have done the same on the Chatham lines, and in the valley on the Chatham side of them; on Norwood Hill, and in the plain at Addiscombe; also on the top of the Monument in London, and on the top of some of the high hills in Westmoreland, and in the North Riding of Yorkshire; and in every case I have found the atmosphere *positive* with regard to the ground. I have floated three kites at the same time at very different altitudes, and have uniformly found the highest to be *positive* to the other two; and the centre kite *positive* to that which was below it: consequently the lowest was negative to the two above it, but still positive to the ground on which I was standing. I have made more than twenty experiments of this kind, and the results (with the exception of electric tension) were invariably the same, showing most decidedly that the atmosphere, in its undisturbed electric state, is more abundantly

charged than the earth, and, as far as I have been able to explore it, still more abundantly in the upper than in the lower strata."

(242) On the evening of the 14th of June, 1834, Mr. Sturgeon sent up a kite during a thunder-storm at Woolwich, and the following is the description he gives of the phenomena observed:—"The wind had abated to such a degree before I arrived in the barrack field, and the rain fell so heavily during the time I was there, that it was with some difficulty that I got the kite afloat, and when up, its greatest altitude, as I imagine, did not exceed fifty yards. The silken cord also, which had been intended for the insulator, soon became so completely wet that it was no insulator at all: notwithstanding all these impediments being in the way, I was much gratified with the display of the electric matter issuing from the end of the string to a wire, one end of which was laid on the ground, and the other attached to the silk at about four inches distance from the reel of the kite-string. An uninterrupted play of the fluid was seen over the four inches of wet silken cord, not in sparks, but in a bundle of quivering purple ramifications, producing a noise similar to that produced by springing a watchman's rattle. Very large sparks, however, were frequently seen between the lower end of the wire (which rested on the grass) and the ground; and several parts of the string towards the kite, where the wire was broken, were occasionally beautifully illuminated. The noise from the string in the air was like to the hissing of an immense flock of geese, with an occasional rattling or scraping sort of noise.

"Two non-commissioned officers of the Royal Artillery were standing by me the whole of the time. Unaware of the consequence, they would very gladly have approached close to the string; and it was not until I had convinced them of the danger of touching or even coming near to it at a time when the lightning was playing about us in every direction, that I could dissuade them from gratifying their curiosity too far—probably at the expense of their lives. We anxiously and steadfastly watched what was going on at the end of the string, and the display was beautiful beyond description. The reel was occasionally enveloped in a blaze of purple arborized electrical fire, whose numberless branches ramified over the silken cord and through the air to the blades of grass, which also became luminous on their points and edges over a surface of some yards in circumference. We also saw a complete globe of fire pass over the silken cord between the wire and the reel of the kite-string. The soldiers thought it about the size of a musket-ball. It was exceedingly brilliant, and the only one that we noticed."

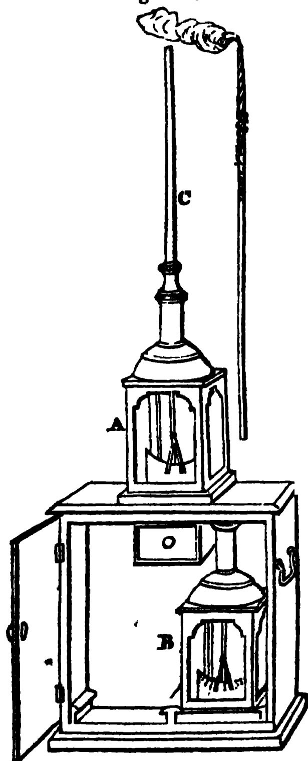
(243) A continuous series of atmospheric electrical observations was conducted under the superintendence of Mr. Ronalds, at the

Kew Observatory, for a period of five years, viz., from August, 1843, to July, 1848, and the results have been discussed at very great length by Mr. Birt, and published in the eighteenth Report of the British Association, 1850. The situation of the observatory is admirably adapted for investigations of this nature. It stands in the old deer park, at Richmond, upon a promontory, formed by a flexure of the river Thames, its least distance from which is 924 feet. The nearest trees (elms) are about 13 feet lower than the top of the conductor, the height of the top of which, above the river at low water, is about 83 feet. The conductor is a conical tube of thin copper, raised 16 feet above the dome of the building, carrying at the top a small lantern or collecting lamp, provided with a little cowl, which can be raised and lowered at pleasure by means of a silk cord. The conductor is firmly screwed into a strong brass tube, which is cemented to a well annealed hollow glass pillar, the lower end of which is trumpet-shaped and ground flat, and is firmly secured to a pedestal. The glass tube is kept constantly warmed by a small oil lamp, the closed copper chimney of which enters but does not actually touch it. The brass tube carries, at its lower end, three or four arms, at right angles to each other, with which the electrometers and other electrical apparatus are connected. The conductor, at the point where it enters the dome, is protected from the weather by an inverted copper dish or parapluie. By this mode of arrangement the active parts of all the electrometers, and the conductor itself, are insulated by one common and efficient insulator. A safety conductor, in good communication with the earth, is attached to the pedestal.

(244) The observations were taken with a Henley's electrometer (Fig. 72), by which the force is measured by a straw terminating in a pith-ball, which, together, constitute a pendulum that is inserted in a ball, working by two fine steel pivots; and by Volta's electrometers, *two* in number. No. 1 is so constructed that a given electric force causes a pair of straws, of known weight, to diverge. Their divergence is measured on a circular arc of the same radius as the length of the straws, which is so graduated as to indicate half the distance in arc between the extremities of the straws, in half Parisian lines, each of the divisions, which are at equal distances from each other, being equal to half a line. It is clear from this construction, that upon measuring the distance between the straws in a right line, "*the sine of half the angle subtended by the extremities of the straws is proportional to the electric tension of the charge.*" No. 2 is so constructed that each division is exactly equal to *five* of No. 1, and the circular arc is graduated to read at once in terms of No. 1. The difference in the electrometer consists in the straws of No. 2 being

heavier than those of No. 1, in such a proportion as to increase the value of the readings in the ratio above mentioned. As in No. 1 the sine of half the angle of divergence is proportional to the tension, so in No. 2 precisely the same value of the tension obtains, viz., the sine of half the angle of divergence, the linear value of the sine itself being proportional to its value in No. 1 for the same force; thus, a force that would diverge the straws in No. 1 to an angle of 30°, would only open those in No. 2 to an angle of 6°, and in each instrument the sine of 15° and 3° respectively would represent the same force. One degree of Henley's Electrometer is *nearly* equal to 100 divisions of Volta, No. 1; and by converting the readings of the latter into measures of arc, Volta No. 1, Volta No. 2, and Henley's may all be expressed in degrees of the circle, the sines of which are readily ascertainable. The Volta Electrometers are placed on the table of the pedestal, with their caps in contact with the conductor, and the Henley is screwed into a ball fixed at the extremity of one of the horizontal arms.

Fig. 114.

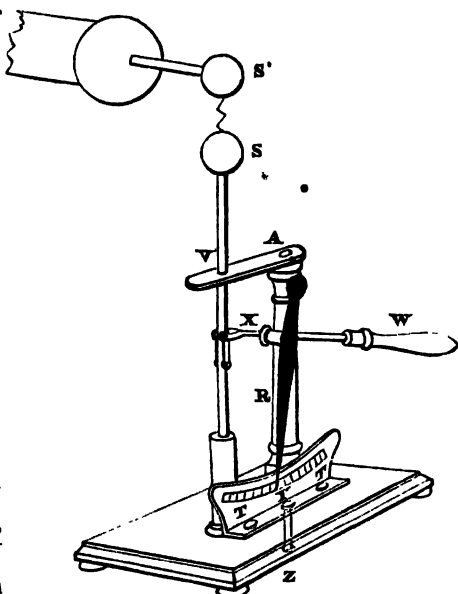


(245) A pair of portable Volta's standard electrometers, used occasionally in experiments on induction, absorption, &c., of atmospheric Electricity, and very useful for observations on mountains, &c., is shown in Fig. 114. The instruments are constructed in strict accordance with Volta's instructions, the straws of one, B, being rendered so much heavier than those of the other, A, that it diverges when both are equally electrified exactly $\frac{1}{5}$th as much. The conductor, C, is a very light conical tube of copper, about 3 feet 6 inches long, which screws on the cap of the Electrometer, and carries on the top a helix of small copper wire, on which, when an observation is about to be made, is placed the lighted *solfanello*, or sulphur candle, of Volta, composed of about 10 threads of lamp cotton coated and imbued with sulphur, while in a melted state. In all cases where the atmospheric charge is not extremely minute, straws are greatly preferable to gold leaves, which can never be safely transported. The conductor,

with its tubes, may be disjointed, and enclosed in a hollow walking cane.

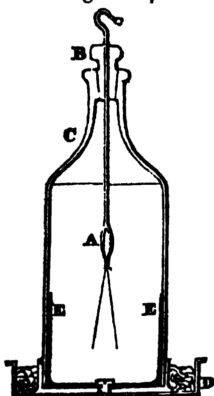
(246) Immediately underneath the extremity of that arm of the conductor upon which the Henley Electrometer is fixed, is placed the *spark measurer* and *safety valve*. This ingenious contrivance is shown in Fig. 115. The length of the spark is measured by means of a long index, R, which exhibits the distance of two balls, S S', from each other on a multiplying scale T T, S being attached to a rod, V, which is raised and lowered by means of a glass handle, W, a forked piece, X, &c. V slides accurately through the base Y, and the piece A. The bolt Z is in immediate communication with the safety conductor. Attached to the extremity of another of the horizontal arms of the conductor is one of the wires of a Gourgon's Galvanometer, for measuring Electricity of high tension. In times of violent rain it gives strong indications, but Mr. Ronalds places no dependence on it as a measurer of Electricity.

Fig. 115.



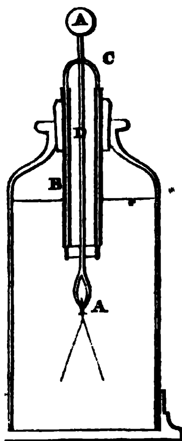
(247) The gold leaf electroscope and the *distinguishing* electroscope used in the Kew Observatory are shown in Figs. 116 and 117. A, Fig. 116, is a wire, terminating below in a pair of forceps, carrying the paper by which the gold leaves are suspended. It passes through a glass stopper, B, which is ground into a long necked bottle, C, with a metallic base, D, and a strip of brass, E E, is bent and screwed to the inside of D. The neck, C, is well covered with sealing-wax, by waxing both inside and out. To preserve the insulating power of the instrument, it is surrounded at its base with an annular tin trough coated with sealing-wax, and containing chloride of calcium, the whole being covered air-tight with a receiver.

Fig. 116.



The distinguisher, Fig. 117, consists of a very thin Leyden phial, C. A is a wire connected with a brass tube, which forms the interior coating of this jar, and B is an exterior coating of the same kind, and these two coatings are at about $\frac{3}{8}$ths of an inch distant from each extremity of the phial. The intervals D C, B C, are coated with sealing-wax inside and out. A, thus prepared, is fitted to a bottle with a metallic base, and is provided with a pair of gold leaves rather too short to reach the sides of the bottle, the neck of which, both inside and out, is covered with sealing-wax. This distinguisher is charged every morning *negatively*, and never fails to retain a good charge for twenty-four hours. It is conveniently placed upon a bracket a few feet distant from the conductor, to which, when used, it is approached by hand to some distance proportionate to the height of the charge. If the charge is positive, the leaves of course collapse more or less, but open again when withdrawn; and if negative the divergence increases, and the operation can be performed without the least danger of lowering the tension of the conductor or injuring the gold leaves, let the height of the charge be what it may.

Fig. 117.



(248) During a period of three years and seven months, viz., from January, 1844, to July, 1848, both inclusive, electrical readings were taken at the Kew Observatory, at each even hour of Greenwich mean time, as well as at sun-rise and sun-set. This long series of observations, amounting to 10,526 readings, furnished materials for deducing the annual and diurnal periods of the electrical tension. The following is a very brief *résumé* of Mr. Radcliffe Birt's elaborate discussion (*Rep. British Assoc.* 1850) of the 10,526 readings; 10,176 were positive, 324 were negative, and 26 were not employed in the discussion. The greatest number of positive observations (1047) were recorded at 8 A.M., and the least number (566) at 6 A.M., but this latter number Mr. Birt considers as probably somewhat too low; the hour of minimum tension appears to be 2 A.M., a gradual rise taking place from that hour until 6 A.M. Between the hours of 6 and 8 A.M. a rapid rise occurs, the tension being nearly doubled: it then increases gradually until 10 A.M., when a maximum is passed, after which it gradually declines until 4. P.M., the epoch of the *diurnal* minimum, as contradistinguished from the *nocturnal* minimum. The tension then rapidly increases until 8 P.M., and at 10 P.M. passes another maximum, rather con-

siderably above the maximum of 10 A.M. From 10. P.M. to midnight the diminution of tension is enormous (81·4 divisions of Volta, No. 1.) The mid-night value is but slightly above the value at 2 A.M., the epoch of the minimum.

(249) *Diurnal period—Summer.*—Of the 10,176 positive observations, 5,514 were taken in the summer months, during which greater uniformity prevailed than during the winter, the means approximated more closely to each other, the general course of the numbers was more regular, and the rise during the morning hours more gentle, though there was still a considerable diminution of tension between 10 P.M. and midnight: 2 A.M. is the epoch of the principal *minimum*, the tension gradually rising until 10 A.M., the forenoon *maximum;* the succeeding *minimum* occurs at noon, gradually rising till 6 P.M., and then rapidly till 10 P.M., the principal *maximum*, from which time till midnight the decline is very considerable.

Winter.—Of the 10,176 positive observations, 4,662 were made in the winter months, during which the range and amount of tension were much greater than in the summer; the *minimum* was at 4 A.M., rising gently to 6 A.M., and rapidly to 10 A.M., the *forenoon maximum*, then gradually sinking till 4 P.M., the *afternoon minimum*, and again rapidly rising till 8 P.M., the epoch of the evening, *evening maximum*, the fall from which till midnight being enormous.

In both winter and summer a *double progression* is most distinctly exhibited. The points of *maxima* and *minima* are well marked; and, in most cases, present a tolerable fixity of epoch. The presence of fog mostly occurring on those occasions when high electrical tensions have been observed, and serene weather being mostly characterised by low tensions, suggested the probability that the forenoon and evening *maxima* result, more or less, from the presence of aqueous vapour, either in an invisible or a condensed state.

(250) *Annual period.*—The discussion shows a march of the electrical tension during the 24 hours, constituting the period of a day. This march presents two well-defined *maxima*, in most instances removed from each other by an interval of twelve hours, the principal occurring at 10 P.M., and the inferior at 10 A.M. Two *minima* have also been ascertained, the principal at 4 A.M., and the subordinate at 4 P.M.: speaking generally in the *diurnal* period, the periods characterised by high and low tensions, are those at which the sun is above and below the horizon; but in the annual period the reverse appears to take place, the highest tension being exhibited during that portion of the year in which the sun is further removed from the northern temperate zone. A general correspondence was shown as to the months exhibiting the greatest degree of humidity and the

greatest electrical tension. The tension at sunset was, with but few exceptions, higher than at sun-rise.

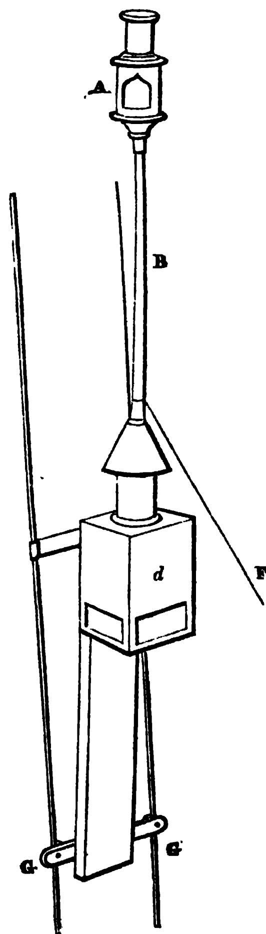
(251) *Negative Electricity.*—The number of readings (324) were too few to deduce anything like a diurnal period, but the great majority of instances in which negative Electricity was exhibited were characterized by two very interesting features. At Kew one of these features was the falling of rain, in most instances heavy, and the other the occurrence of *cirro-strati*, and occasionally of *cumulo-strati*, which clouds were considered as having contributed their quota to the development of the Electricity observed. On one occasion (June 10, 1844), *previous* to the fall of any rain, the Henley electrometer rose to 90° P., and sparks $1\frac{1}{2}\frac{9}{0}$ inch in length passed from the conductor. The charge changed to N. shortly after the rain began, rising to 55° of Henley, and sparks $\frac{9}{20}$th of an inch were obtained. These high signs lasted about a quarter of an hour, but the charge of negative Electricity remained a considerable time after the rain had ceased, gradually diminishing. Although the small number of observations did not furnish data sufficient to determine a diurnal period, they pointed out a connexion between negative readings and the prevalence of clouds, when there was no rain, for though negative Electricity is *generally*, it is not always, accompanied by the falling of rain, nor is all rain accompanied by negative Electricity; and, upon the whole, it was considered that negative readings are indications of considerable disturbances which are of a systematic character, and that, like positive Electricity, negative is also subject to well defined laws of diurnal periodicity.

(252) The development of the electric force in the act more or less of the condensation of vapour is considered by Mr. Birt (*Phil. Mag.*, vol. xxxvi. p. 161) as a point of peculiar prominence, and he believes that the entire process of nubification is intimately connected with this development, the different modifications of cloud being entirely dependent on the presence or absence of a disturbed electrical state. Not only when the condensation is effected, but when no previous disturbed state exists, it may actually be brought about by the condensation of vapour; indeed he appears disposed to consider the condensation of vapour as the most productive source of the Electricity of the atmosphere. R. Phillips (*Phil. Mag.*, vols. xxxv. and xxxvi.) adopts the same view. In his experiments on the Electricity of steam he found that a jet of steam imparts positive Electricity to any substance that it touches, while at the same time the steam may as a whole be more or less negative. When particles of water are projected through a steam cloud they are supposed to collect together the minute positive particles, thus becoming them-

selves positive, leaving the gaseous matter negative. In this way electrical developments may occur in the atmosphere, and lightning may result from the rapid condensation of the steam cloud, the descending rain and mist being positive, leaving the upper regions negative. According to this theory the tendency of lightning is to render the upper regions negative, and when the air is thus highly charged, if a column of mist sufficiently high and dense were interposed between the negative heavens and the positive earth, a series of disruptive discharges would take place which Phillips suggests may be the aurora.

(253) The development of Electricity by condensation alone is shown by the following experiments. If a jet of water be passed through a jet of steam in the same direction as the steam is passing, the water receives a charge of *negative* Electricity. If steam alone, or water alone, be introduced into a tin pipe, no electrical effects are exhibited; but if steam and water be mixed a *positive* charge is indicated. Great increase in the fall of rain *previous* to the occurrence of lightning has been noticed by several observers; and Mr. Birt's answer to the question—"Is the sudden gush of rain which is almost sure to succeed a violent detonation a *cause* or a *consequence* of the electric discharge?"—seems a satisfactory one. The rain in most cases *precedes* the lightning flash, which is the result of the agglomeration of many minute and feebly electrified globules into one rain-drop, by which the quantity of Electricity is increased in a greater proportion than the surface over which it is spread: the tension is therefore increased, and at last becomes enormous, and the flash escapes.

Fig. 118.



(254) Fig. 118 represents the arrangement of the exploring conductor at the Meteorological Royal Observatory at Greenwich, under the superintendence of Mr. Glaisher. B is a copper tube, on which the lantern, containing a lamp, A, which is always burning, slides. The rod

is supported on a cone of glass, the lower part of which is hollowed out and lined with copper, immediately under which is, in the wooden apparatus *d*, placed a lamp, which is kept constantly burning for the purpose of heating the copper, and thus keeping the glass dry. The glass cone is protected from rain, &c., by a copper umbrella, from which proceeds the wire F, communicating with the electrical instruments in the ante-room. The whole apparatus slides up and down the iron rods G G. The measuring instruments are the same as those employed at Kew, with the addition of a pair of Bohnenberger's single-leaf pendant gold leaf electroscopes, with Zamboni's dry electric piles (Fig. 10, p. 30); but as the communicating wire F has to pass for a considerable distance through the atmosphere in an unprotected state, a great portion of the charge must be lost by dissipation and radiation before it arrives at the apparatus room. There are likewise seve.al large trees in the immediate neighbourhood of the conductor. We believe, however, that it is in contemplation to erect an exploring conductor after the exact model of the one at Kew, on the summit of the Astronomical Observatory, a position in every respect unexceptionable.

(255) A very valuable instrument for observing the Electricity of the atmosphere, simple in its construction and certain in its results, of which any number may be made perfectly comparable with each other, was invented by the late M. Peltier, and called by him the *Induction Electrometer*. It is thus constructed (*Rep. Brit. Assoc.*, 1849): a hollow ball of copper, four inches in diameter, is placed at the top of a rod of the same metal, which is terminated at its lower extremity by a much smaller ball. From the last mentioned ball, insulated from the glass cover by a lump of shell-lac, descends a copper rod which bifurcates and forms a kind of ring. At the centre of this ring a small copper needle, which forms the essential part of the instrument, moves freely balanced on a pivot. When the Electrometer is in its natural state the needle is brought to the magnetic meridian by a much smaller magnetic needle, which is parallel to it, and fixed immediately above it. Another copper needle, much thicker than the moveable one, forms a system with the rod which descends into a glass tube filled with shell-lac, and fixed into the wooden stand. Thus the entire metallic part of the apparatus is insulated, and Electricity can be communicated from it neither to the glass cover nor the stand. This insulation must be established with the greatest care. The stand is furnished with three levelling screws, which enable it to be placed horizontally. To prepare the instrument for an observation, it must be so placed that the fixed needle shall be in the direction of the magnetic meridian. In this

position the moveable needle, directed by its small magnetic needle, places itself parallel to the fixed needle. If now a body electrified, positively or negatively, be held over the ball, it decomposes by induction. The Electricity of this ball and its metallic appendages. If the body be positively electrified at the upper extremity of the ball, the negative Electricity by the positive Electricity *in presence*, while in the lower part of the instrument the free positive Electricity causes the small needle to diverge from the position which it had at first, and its angle of deviation from the fixed needle will be greater as the free Electricity is more considerable. The angle of deviation is read off by means of two graduated circles, one of which is pasted to the stand, and the other to the glass cover, by this, parallax is avoided in the readings. If while the ball is influenced by external Electricity the stem be touched, the free Electricity, which we will assume to be positive, will be removed, and the needle will replace itself in the magnetic meridian. If the inducing body which coerces the negative Electricity at the upper part of the ball be removed immediately after, the Electricity will become free, and the moveable needle will diverge anew.

(256) When an observation is to be made with this instrument, it is placed on a stand raised about 6 feet, and the stem touched as low as possible with a thin metallic wire to put it into electric equilibrium: the hand is kept at as great a distance from the instrument as possible to avoid inductive action. The equilibrium being established, when the Electrometer is elevated, it gives signs of *negative* Electricity when lowered, while on being raised it indicates *positive*. When the operation (which may be completed in eight or ten seconds) is thus performed, this change of sign must be taken into consideration, in order not to attribute a contrary Electricity to the atmosphere. In like manner a *negative* tension of the atmosphere is indicated, when the instrument on being lowered, gives a *positive* sign. The indications afforded by this Electrometer are simpler and more readily interpreted than atmospheric electrometers of the usual construction. It is affected only by the inductive action of the atmosphere, or rather by the difference of the inductive actions of the earth, and its superincumbent atmosphere, however the instrument be raised above or depressed below its point of equilibrium, or however the inductive action of the atmosphere may change while it remains in the same position, it neither receives nor loses Electricity, its *distribution* only is changed. But if, instead of a polished ball, the stem be terminated with a point, a bundle of points, or a lighted wick, as in Volta's experiments, to the phenomenon of induction there is added another, which complicates, and sometimes disguises

it; the uncoerced Electricity radiates into space, and though this radiation is greater as the induction is more powerful, yet it is also greatly influenced by the moisture of the air, rain, and the force of the wind, none of which circumstances affect in any obvious degree the induction electrometer.

(257) A regular and uninterrupted series of observations was made with this instrument by M. Quetelet at the Royal Observatory in Brussels, from the beginning of August, 1844, till the end of December, 1848, and the results were published in the *Annales de l'Observatoire Royale de Bruxelles*, tom. vii. 1849. His experiments show that, 1st, the atmospheric Electricity, considered in a general manner, attains its *maximum* in January, and progressively decreases till the month of June, which month presents a minimum of intensity: it augments during the following months till the end of the year. 2nd. The maximum and minimum of the year have for their respective values 605 and 47; so that the Electricity in January is *thirteen* times more energetic than in the month of June. The mean value of the year is represented by the values given by the months of March and November. 3rd. The absolute maxima and minima of each month follow a course precisely analogous to that of the monthly means; the means of these extreme terms equally produce the annual variation, although in a less decided manner. Quetelet also determined that the difference between the maximum and minimum is much more sensible in serene than in cloudy weather, but that in the months of June and July, when the Electricity attains its minimum, the reading is very nearly the same whatever be the state of the sky. He frequently noticed a strong Electricity, either positive or negative, at the approach or cessation of rain. During the whole four years included in his register, the Electricity was observed to be *negative* only twenty-three times, and these indications generally either preceded or followed rain and storms.

(258) The following conclusions, deduced by M. Quetelet from his observations made to ascertain the diurnal variations of the Electricity of the air, are in very close accordance with those of Mr. Birt, as deduced from the Kew observations. 1st. The Electricity of the air, estimated always at the same height, undergoes a diurnal variation, which generally presents two maxima and two minima. 2nd. The maxima and minima vary according to the different periods of the year. 3rd. The first maximum occurs in summer before 8 A.M., and towards 10 A.M. in winter: the second maximum is observed after 9 P.M. in the evening in summer, and towards 6 P.M. in the winter. The interval of time which separates the two maxima

is therefore more than thirteen hours at the epoch of the summer solstice, and eight hours only at the winter solstice. 4thly. The minimum of the day presents itself towards three o'clock in the summer, and towards one o'clock in winter. The observations were insufficient to establish the progress of the night maximum. 5thly. The instant which best represents the mean electric state of the day, in the different seasons, occurs about eleven in the morning.

(259) The principal source of atmospheric Electricity was formerly supposed to be evaporation from the earth's surface. The researches of Faraday and others into the phenomena of the hydro-electric machine (111 *et seq.*) have, however, induced Electricians to modify their views on this subject. M. Peltier has, indeed, endeavoured to prove (*Annales de Chimie et de Physique*, t. 4, 3rd series) that vapour produced at a temperature below 230° Fahr. never carries off free Electricity, and that as this temperature is not that of the surface of the globe, the electric vapours that rise cannot proceed from the simple evaporation of saline or pure waters. Whence then does the Electricity of clouds and fogs proceed? According to Peltier's views, the terrestrial globe is a body charged with *resinous* Electricity, and the vapour which rises from it being *resinous* like itself, its tension reacts downwards against that of the globe, and successively reduces all its effects. But as vapour is to a certain extent conducteous, it does not long retain the equal distribution of its resinous tension. The incessant action of the globe repels the *resinous* Electricity towards the upper strata, and thus renders the lower strata *vitreous*. The denser the vapour, the more easily this is done. Accordingly it is found that towards evening, when condensation is taking place, the electrometer gives higher indications than in the middle of the day. Every body situated on the surface of the earth shares in its *resinous* tension. The more it projects into space, the more does this tension increase. Thus, mountains, edifices, and even organized beings, have greater degrees of *resinous* tension than the soil on which they rest. The electrometer exhibits a greater divergence under condensed vapours compacted into clouds, because the influence of the earth renders these clouds more *resinous* in the upper part than in the lower. As long as an insulated body remains in a state of equilibrium of reaction, it can give no manifestation of induced Electricity. The leaves of an induction electrometer remain at rest as long as the instrument is stationary, but when it is elevated or depressed, they acquire either a *less resinous* (*vitreous*) or a *more resinous* tension, because the reaction of the globe no longer operating in the same proportions over the instrument, the resinous Electricity becomes differently distributed; it increases towards the upper part

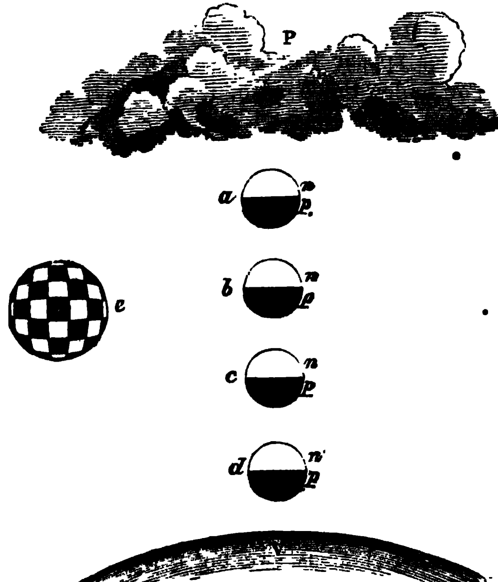
when the electrometer is elevated, and becomes dominant in the lower portion when it is depressed, hence the leaves diverge in the former case with *vitreous*, and in the latter with *resinous* Electricity. Peltier applied his theory to the explanation of the various forms of clouds and fogs, and various other meteorological phenomena. We must refer our readers to his various memoirs. *Annales de Chimie et de Physique*, t. iv. 3rd series; *Bulletins de l'Académie Royale de Bruxelles*, 1842-3; *Traité des Trombes; Comptes Rendus from* 1838 *to* 1842.

(260) The analogy between the electric spark and lightning was noticed at an early period of electrical science. In 1708 Dr. Wall mentioned a resemblance between Electricity and thunder and lightning. In 1735 Mr. Grey *conjectured* their identity, and that they differed in *degree* only; and in 1748 the Abbé Nollet reproduced the conjecture of Grey, attended with more substantial reasons; but it was reserved for the great American philosopher, Franklin, to *demonstrate* the identity by the bold experiment of bringing down lightning from the heavens by means of a kite, and of performing with it experiments similar to those usually made with ordinary Electricity. The circumstances connected with this brilliant discovery have been fully detailed in our introductory chapter (16).

(261) Lightning and thunder, then, are atmospheric electrical phenomena, and the terrific thunder-storm must be regarded as indicating the process by which nature disposes from time to time of an excess of that Electricity which is required and generated for the purpose of carrying on the process of vegetation, and probably also of animal life. A thunder-storm is the result of an electrical disturbance arising from the accumulation of active Electricity in masses of vapour (clouds), condensed in the atmosphere. Agreeably with the laws of induction, a mass of electrified vapour determines an opposite electrical state over that portion of the earth's surface directly opposed to it; the particles of intervening air assume a peculiar forced electrical state, which has been termed *polarized*, and when the tension has been raised to a certain point, and the particles can no longer resist the tendency of the opposite electrical forces to combine, they are displaced and broken through with a greater or less degree of mechanical violence. Thus, in Fig. 119, let P represent a mass of clouds charged with positive Electricity, and V the opposed portion of the earth's surface rendered inducteously negative; *a, b, c, d* may be taken to represent four particles of intermediate air, the electrical forces in which are, under the influence of the cloud, no longer distributed in a state of inactivity over their surface, as shown in *e*, where the black squares may be

taken to represent the positive force, and the unshaded squares the negative force, but are arranged in what may be termed a polar

Fig. 119.



manner, with their opposite electrical forces concentrated on each of their opposite faces, and the lightning flash is an indication of the return of the particles to their normal condition by disruptive discharge (124) between them. The clouds and the earth, or two oppositely electrified clouds, correspond to the coatings, and the intervening air to the glass, of the Leyden phial, and the thunder-storm is the charging and discharging of this huge system.

(262) The appearance of the heavens previous to and during a thunder-storm was first diligently studied by Beccaria.* He noticed that a dense cloud was first formed, increasing rapidly in magnitude, and ascending into the higher regions of the atmosphere. The lower end is black, and nearly horizontal; but the upper is finely arched, and well defined. Many of these clouds often seem piled one upon the other, all arched in the same manner; but they keep constantly uniting, swelling, and extending their arches. When such clouds rise, the firmament is usually sprinkled over with a great number of separate clouds of odd and bizarre forms, which keep quite motionless. When the thunder-cloud ascends; these are drawn

* Lettre dell' Elettricismo, Bologna, 1758.

towards it, and as they approach they become more uniform and regular in their shapes, till coming close to the thunder-cloud their limbs stretch mutually towards each other, finally coalesce, and form one uniform mass. But sometimes the thunder-cloud will swell and increase without the addition of these smaller adscititious clouds. Some of the latter appear like white fringes at the skirts of the thunder-cloud, or under the body of it; but they continually grow darker and darker as they approach it.

(263) When the thunder-cloud, thus augmented, has attained a great magnitude, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into large protuberances, tending uniformly towards the earth; but sometimes one whole side of the cloud will have an inclination to the earth, which the extremity of it will nearly touch. When the observer is under the thunder-cloud after it is grown large and is well formed, it is seen to sink lower and to darken prodigiously, and at the same time a great number of small clouds are observed in rapid motion driven about in irregular directions below it. While these clouds are agitated with the most rapid motions, the rain generally falls in abundance; and if the agitation be very great, it hails.

While the thunder-cloud is swelling and extending itself over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes between the cloud and the earth in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer does the cloud grow, and the less dark in its appearance, till it breaks in different places, and shows a clear sky. When the thunder-cloud is thus dispersed, those parts which occupy the upper regions of the atmosphere are spread thinly and equally, and those that are beneath are black and thin also, but they vanish gradually, without being driven away by the wind.

(264) The following is the account given by Dr. Thomson:—"A low dense cloud begins to form in a part of the atmosphere that was previously clear. This cloud increases fast, but only from its upper part, and spreads into an arched form, appearing like a large heap of cotton wool. Its under surface is level, as if it rested on a smooth plane. The wind is hushed, and everything appears preternaturally calm and still.

"Numberless small ragged clouds, like teaseled flakes of cotton, soon begin to make their appearance, moving about in various direc-

tions, and perpetually changing their irregular surface, appearing to increase by gradual accumulation. As they move about, they approach each other, and appear to stretch out their ragged arms towards each other. They do not often come into contact, but after approaching very near each other, they evidently recede, either in wholes or by bending away their ragged arms.

"During this confused motion, the whole mass of small clouds approaches the great one above it; and when near it, the clouds of the lower mass frequently coalesce with each other before they coalesce with the upper cloud; but as frequently the upper cloud coalesces without them. Its lower surface, from being level and smooth, now becomes ragged, and its tatters stretch down towards the others, and long arms are extended toward the ground. The heavens now darken apace, and the whole mass sinks down. Wind rises and frequently shifts in squalls. Small clouds move swiftly in various directions. Lightning darts from cloud to cloud. A spark is sometimes seen co-existent through a vast horizontal extent of a zig-zag shape, and of different brilliancy in different parts. Lightning strikes between the clouds and the earth, frequently in two places at once,—a heavy rain falls,—the cloud is dissipated, or it rises high and becomes light and thin. These electrical discharges obviously dissipate the Electricity:—the cloud condenses into water, and occasions the sudden and heavy rain which always terminates a thunder-storm. The previous motions of the clouds, which act like electrometers, indicate the electrical state of different parts of the atmosphere."

(265) A great difference will be observed in the appearance of the flashes of lightning during a thunder-storm. The scene is sometimes rendered awfully magnificent by their brilliancy, frequency, and extent; darting sometimes, on broad and well-defined lines, from cloud to cloud, and sometimes shooting towards the earth; they then become zig-zag and irregular, or appear as a large and rapidly-moving ball of fire—an appearance usually designated by the ignorant a *thunder-bolt*, and erroneously supposed to be attended by the fall of a solid body. The report of the thunder is also modified according to the nature of the country, the extent of the air through which it passes, and the position of the observer. Sometimes it sounds like the sudden emptying of a large cart-load of stones; sometimes like the firing of a volley of musketry: in these cases it usually follows the lightning immediately, and is near at hand: when more distant it rumbles and reverberates, at first with a loud report, gradually dying away and returning at intervals, or roaring like the discharge of heavy artillery. In accounting for these phenomena, it must be remembered that the passage of Electricity is almost infinitely rapid.

A discharge through a circuit of many miles has been experimentally proved to be instantaneous: the motion of light is similarly rapid; and hence the flash appears momentary, however great the distance through which it passes: but sound is infinitely slower in its progress, travelling, in air, with a velocity of only 1130 feet in a second, or about twelve miles in a minute. Now, supposing the lightning to pass through a space of some miles, the explosion will be first heard from the point of the air agitated nearest the spectator; it will gradually come from the more distant parts of the course of the Electricity; and, last of all, will be heard from the remote extremity: and the different degrees of the agitation of the air, and likewise the difference of the distance, will account for the different intensities of the sound and the apparent reverberation and charges.

(266) Thunder only takes place when the different strata of air are in different electrical states: the clouds interposed between these strata are also electrical, and owe (according to Dr. Thomson) their vesicular nature to that Electricity. They are also conductors. The discharges usually take place between two strata of air; more rarely between the air and the earth; and sometimes without noise, in which case the flashes are very bright: but they are single, passing visibly from one cloud to another, and confined, usually, to a single quarter of the heavens. When the discharge is accompanied by thunder, a number of simultaneous and different-coloured flashes may generally be observed stretching to an extent of several miles. These seem to be occasioned by a number of successive discharges from one cloud to another, the intermediate clouds serving as intermediate conductors, or stepping-stones as it were, for the electric fluid. It is these discharges which occasion the rattling noise. Though they are all made at the same time, yet, as their distances are different, they only reach the ear in succession, and thus occasion the lengthened rumbling noise—so different from the snap which accompanies the discharge of a Leyden jar.

(267) The snap attending the spark from the prime conductor of an electrical machine and the awful thunder-crash are undoubtedly similar phenomena, and produced by the same action. The cause is the vibration of the air agitated by the passage of the electric discharges with a greater or less degree of intensity: and two explanations may be given of the manner in which the vibration is produced. On the one hand, it may be imagined that the electric fluid opens for itself a passage through air, or other matter, in the manner of a projectile, and that the sound is caused by the rush of the air into the vacuum produced by the instantaneous passage of the fluid: or, on the other hand, the vibration may be referred to a decomposition

and recomposition of Electricity in all the media in which it appears. On this hypothesis, the continued roll is the effect of the comparatively slow propagation of sound through the air, and it may be thus illustrated.* Suppose a flash of lightning 11,300 feet in length, or that the spark is instantaneously seen from one end to the other of this line. At the same instant that the flash is visible the vibration is communicated to the atmosphere through the whole extent of the line. Now suppose an observer placed in the direction of the line of the flash, and at the distance of 1,130 feet from one end: then, since sound travels at the rate of 1,130 feet in a second, *one* second will elapse after the flash has been seen before any sound will be heard. When the sound begins, the vibration communicated to the nearest stratum of air has reached his ear; and since the line of disturbance has been supposed to be 11,300 feet in length, the vibrations of the more distant strata will continue to reach his ear in succession, during the space of *ten seconds*. Hence, the length of the flash determines the duration of the sound: and it follows that the same flash will give rise to a sound of greater or less duration, according to the position of the observer with respect to its direction. Thus, in the above instance, suppose a second observer to be placed under the line, and towards its middle, he would only hear the sound during half the time it was heard by the first observer; and if we suppose the line to be circular, and the observer to be placed near its centre, the sound would arrive from every point at the same instant in a violent crash.

(268) Although the vibratory motion is communicated to all the strata of air along the whole length of the flash, they will not all receive the same impulsion unless they are all at the same temperature, and in the same hygrometric state, which can rarely happen. Hence, although proceeding from the nearest point, the first impression of the sound is not always the most intense.

The latter of these two ways of accounting for the vibration, seems to accord best with facts; for, in the first place, it has been objected that if the noise were occasioned by the electric fluid forcing for itself a passage through the air, a similar sound ought to be produced by a cannon-ball: and a still stronger objection is, that experiments seem to indicate that the electric fluid is not transferred from point to point like a projectile of ponderable matter, but by the vibration of an elastic medium, as sound is conveyed through the atmosphere.

The equilibrium of the clouds is sometimes restored by a single flash of lightning: at other times the accumulation is so immense,

* See Brand's Dictionary of Science, Literature, and Art. Article, *Thunder*.

and the neighbouring strata of air so strongly charged, that the flashes continue for hours before they terminate in a storm of rain.

(269) A person may be killed by lightning, although the explosion takes place twenty miles off, by what is called the back stroke. Suppose that the two extremities of a cloud highly charged hang down to the earth, they will repel the Electricity from the earth's surface if it be of the same kind as their own, and will attract the other kind: if a discharge should suddenly take place at one end of the cloud, the equilibrium will instantly be restored by a flash at that point of the earth which is under the other. Though this back stroke is often sufficiently powerful to destroy life, it is never so terrible in its effects as the direct shock.

When a building is struck by lightning, the charge is generally determined towards the chimney, owing to its height, and to the conducting power of the carbon deposited in it; for it has been demonstrated experimentally, that the electric fluid will pass with facility to a considerable distance over a surface of carbon.

(270) This is illustrated in the following account of the effects of a terrific flash which struck the house of Mr. Thomas Smith, at Brabourn, in Kent (*Elect. Mag.* July, 1846). "Mr. Smith was roused by hearing a tremendous crash in the adjacent room, in which five of his children were sleeping. On reaching the room *he found the chimney levelled from the top to the floor*, the bricks and rubbish nearly covering it, and some portion of the bed. The children were fortunately unhurt with the exception of one, the eldest, a boy about thirteen years of age, who received a severe contusion from one of the falling bricks on the left eye. Their escape was almost miraculous, as one of the bedposts was shivered into splinters, and the pillows were actually driven from under the heads of the children, one entirely through the door, the panels of which were forced out and the other left hanging in the aperture, the bed-clothes were afterwards found to be ignited in two places, each about the size of half a crown, but by timely attention further calamity was prevented. On afterwards examining the premises it was found that the electric fluid had passed down the stairs, through the back wash-house to the hog-sty, wherein were two fine animals weighing each about seven score; one was struck dead, and the other escaped unhurt. The house was so much damaged that it was thought necessary to take it down."

(271) Again, in the following account contained in a letter to Mr. Weekes from Mr. Layton of Sandwich (*Elect. Mag.* vol. ii. p. 123). "I was watching the lightning at four o'clock in the morning (July 3, 1846), as I lay in bed, when my eye was attracted by a momentary blaze *between the fire-place and the window*, just beyond my bed curtain,

attended by a very loud, sharp, stunning noise; it seemed like the discharge of a cannon, a volley of mortar fragments flew all over the room. Afterwards, a second perhaps, came the thunder. The blaze was elliptic, about four feet horizontally, as perfectly distinct as the blaze of a gas light; its outline however was not defined like that which is compressed by the atmosphere, while here, the pressure being sudden and from within, the border was diluted and rugged. The stench was abominable, it seemed as if driven into the substance of every thing in the room. Nothing was burnt. On examination the electric body *appeared to have entered the chimney through the side of the pot, in which it made a hole large enough to admit two fingers*, and which it forced about eight inches from its place; it then descended some twenty or five and twenty feet, when it came through a crack in the front of the chimney, and burst the paper, forcing out the canvas without tearing it, as if the blunt end of a stick had been pushed against it; thence it passed downwards between the bricks and the canvas till it met obstruction in the wooden mantel-shelf fastened to the bricks, when it broke into the room bursting both canvas and paper, and forcing the wood-work about an inch forward; the flash in this case probably divided, the principal current descending the funnel in a direct line to the earth, while another portion passed off laterally through the wall from whence it burst into the bed chamber."

(272) The directions to be given as to the best positions of safety during a thunder-storm are few and simple. If out of doors, trees should be avoided; and if from the rapidity with which the explosion follows the flash it should be evident that the electric clouds are near at hand, a recumbent posture on the ground is the most secure. It is seldom dangerous to take shelter under sheds, carts, or low buildings, or under the arch of a bridge: the distance of twenty or thirty feet from tall trees or houses is rather an eligible situation, for, should a discharge take place, these elevated bodies are most likely to receive it, and less prominent bodies in the neighbourhood are more likely to escape. It is right also to avoid *water*, for it is a good conductor; and the height of a human being near the stream is not unlikely to determine the direction of a discharge. Within doors we are tolerably safe in the middle of a carpeted room, or when standing on a double hearth rug. The chimney, for reasons above stated, should be avoided: upon the same principle, gilt mouldings, bell-wires, &c., are in danger of being struck. In bed we are tolerably safe—blankets and feathers being bad conductors, and we are, consequently, to a certain extent, insulated. It is injudicious to take refuge in a cellar, because the discharge is often from the earth to a

cloud; and buildings frequently sustain the greatest injury in the basement story.

(273) Arago* divides the phenomena of lightning into three classes. In the first he places those luminous discharges characterized by a long streak of light, very thin, and well defined at the edges; they are not always white, but are sometimes of a violet or purple hue; they do not move in a straight line, but have a deviating track of a zigzag form. They frequently divide in striking terrestrial objects, into two or more distinct streams, but invariably proceed from a single point. Under the second class Arago has placed those luminous effects not having any apparent depth, but expanding over a vast surface; they are frequently coloured red, blue, and violet; they have not the activity of the former class, and are generally confined to the edges of the cloud from which they appear to proceed. The third class comprises those more concentrated masses of light which he has termed globular lightning. The long zigzag and expanded flashes exist but for a moment, but these seem to endure for many seconds; they appear to occupy time, and to have a progressive motion.

"It is more than probable," observed Sir W. Harris (*Essay on the Nature of Thunder-storms*, p. 35), "that many of these phenomena are at last reducible to the common progress of the disruptive discharge, modified by the quantity of passing Electricity, the density and condition of the air, and the brilliancy of the attendant light. When the state of the atmosphere is such that a moderately intense discharge can proceed in an occasionally deviating zigzag line, the great nucleus or head of the discharge becomes drawn out as it were into a line of light visible through the whole track; and if the discharge divides on approaching a terrestrial object, we have what sailors call *forked lightning;* if it does not divide, but exhibits a long rippling line, with but little deviation, they call it *chain lightning.* What sailors term *sheet lightning* is the light of a vivid discharge reflected from the surfaces of distant clouds, the spark itself being concealed by a dense intermediate mass of cloud, behind which the discharge has taken place. In this way an extensive range of cloud may appear in a blaze of light, producing a truly sublime effect. The appearance termed *globular lightning* may be the result of similar discharges; it is no doubt always attended by a diffusely luminous track; this may, however, be completely eclipsed in the mind of the observer by the great concentration and density of the discharge, in the points immediately through which it continues to force its way, and where

* Annuaire du Bureau des Longitudes, pour 1838.

the condensation of the air immediately before it is often extremely great. It is this intensely illuminated point which gives the notion of globular discharge: and it is clear, from the circumference of air which may become illuminated, the apparent diameter will often be great. Mr. Hearder, of Plymouth, once witnessed a discharge of lightning of this kind on the Dartmoor Hills, very near him. Several vivid flashes had occurred before the mass of clouds approached the hill on which he was standing; before he had time to retreat from his dangerous position, a tremendous crash and explosion burst close to him. To use his own words, 'the spark had the appearance of a nucleus of intensely ignited matter, followed by a flood of light; it struck the path near me, and dashed with fearful brilliancy down its whole length, to a rivulet at the foot of the hill, where it terminated.'"

(274) That the appearances termed *fire-balls* must be regarded as peculiar forms of disruptive discharge is evident from the following cases furnished by Mr. Chambers, as occurring on board the "Montague;" and by Captain Stewart, commander of the Hon. East India Company's ship "Lady Melville." In Mr. Chambers' account (*Phil. Trans.* vol. xlvi. p. 336) it is stated that whilst engaged in taking an observation on the quarter-deck, one of the quartermasters requested him to look to windward; upon which he observed a large ball of blue fire rolling along on the surface of the water, as big as a mill-stone, at about three miles distant. Before they could raise the main tack, the ball had reached within forty yards of the main-chains, when it rose perpendicularly with a fearful explosion, and shattered the maintop-mast in pieces.

The account from the journal of the "Lady Melville" (*Elect. Mag.* vol. i. p. 283) is as follows:—

"At four, P.M., a great deal of wind; lightning and heavy black clouds passing over head; at half-past six a *ball of fire struck the mainmast*, passed through the upper deck, making a hole about eighteen inches in diameter and four feet from the mast, when it exploded on the gun-deck with a tremendous noise, and forcing the deck upwards abaft the mainmast. About a quarter past seven another ball of fire struck the mainmast, and ascending upwards and passing through the centre of the mast, it exploded with a loud crackling noise like a roll of musketry, with vivid sparks, breaking several of the large iron hoops which surround the mast, and scattering the fittings in all directions. A sailor, on approaching the hole on the deck, was scorched so severely from *below upwards*, that he died twelve days after in extreme agony. The compass was not affected, nor was there any smell."

In June, 1826, two young ladies were struck dead by lightning on the Malvern Hills, and it was stated (*Lloyd's Evening Post*) that the electric discharge appeared as "a mass of fire rolling along the hill towards the building in which the party had taken shelter."

Harris thinks that in many cases, in which distinct balls of fire of sensible duration have been perceived, the appearance has resulted from the species of brush or glow discharge (127—135) which may often precede the main shock. In short, it is not difficult to conceive, that before a discharge of the whole system takes place, that is to say, before the constrained condition of the dielectric particles of air intermediate between the clouds and the earth becomes as it were overturned, the particles nearest one of the terminating planes or other bodies situate on them may begin to discharge upon the succeeding particles, and make an effort to restore the natural condition of the system by a gradual process.

If therefore we conceive the discharging particles to have a progressive motion from any cause, then we shall immediately obtain such a result as that observed by Mr. Chalmers, on board the "Montague," in which a large ball of blue fire was observed rolling on the surface of the water towards the ship from *to-windward*. This was evidently a sort of *glow discharge*, or *St. Helmo's fire*, produced by some of the polarized atmospheric particles yielding up their Electricity to the surface of the water. The clouds were in rapid motion: the discharging particles had motion towards the ship, the rate of which appears from the account, to correspond with the velocity of the breeze. On nearing the ship, the point of discharge became transferred to the head of the mast: and the striking distance being thus diminished, the whole system returned to its normal state, that is to say, a disruptive discharge ensued between the sea and the clouds, producing the usual phenomena of thunder and lightning, termed by the observers, the "rising of the ball through the mast of the ship." The fatal occurrence on the Malvern Hills, is another instance of the same kind. It is therefore highly probable that these appearances so decidedly marked as concentrated balls of fire, are produced by the glow or brush discharge, producing a St. Helmo's fire in a given point or points of a charged system previously to the more general and rapid union of the electrical forces: whilst the greater number of discharges described as globular lightning, are, as already observed, most probably nothing more than a vivid and dense electrical spark in the act of breaking through the air, which, coming suddenly on the eye, and again vanishing in an extremely small portion of time, has been designated a ball of light.*

* Nature of Thunder-storms, p. 39.

(275) Some very remarkable appearances of lightning, during a terrific storm which occurred in the neighbourhod of Manchester, on the 16th of July, 1850, were observed by Joule (*Phil. Mag.*, vol. xxxvii.), and Clare (*ibid.* p. 336). Each discharge appeared to emanate from a mass of clouds in the S. W., and travelled six or ten miles in the direction of the spectator, dividing into half a dozen or more sparks or zig-zag streams of light, and *not striking the ground*, the elevation being apparently about three and half miles. A remarkable feature noticed by both observers was the sensible *time* of its travelling. The main streams were formed before the diverging sparks, and when formed, remained steady for an appreciable time. The flashes from cloud to cloud presented a great variety of forms and ramifications; sometimes appearing like the branched roots of trees, and occasionally with bright balls at the termination of all or some of the branches.

(276) The most appalling description of the phenomena attending some thunder-storms that we have met with, is in a communication from Mr. S. Strickland to the *Electrical Magazine* (vol. ii. p. 125). We quote certain parts of this description as illustrating the identity of *fire-balls* with electric discharges. "I was soon startled by seeing a fire-ball pass before me, within a few yards of my gun, and strike a small tree; others passed me; some having streams or tails several yards in length, and all about eight or nine feet from the ground: they all ended by striking one or other of the trees, within two hundred yards of me: some passed over my head, others stopped short and struck the trees in the wood; they all uttered a a cauldron-like roar as they passed, and gave out a crackling din as they terminated their career. Dreading the close vicinity of these fire-balls, I lay at full-length on the ground watching and counting them as they flew: I observed that each spark spread to the size of the double fist, and emitted a dazzling light of a brilliant silvery whiteness. This scene lasted for more than a quarter of an hour, when the approach of a heavy fall of rain induced me to crawl to my gun, in order that I might protect it from the wet. I instantly felt what resembled the fall of a heavy wool-sack on my head: the feeling passed down my chest, producing involuntarily a deep sob, and then down my stomach, producing a sensation of deadly sickness, and a horrid smell of sulphur on my clothes. A violent shower fell, accompanied by large transparent pieces of ice, about an inch and a half long, and three-quarters of an inch wide, broken at the end. Never less than two, and frequently as many as *five* fire-balls were in view at the same time: their flight was not so rapid as to be called instan-

taneous, for I could at times watch one through its course before another appeared; they all ended with two or more crackling reports, crossing each other in all directions, striking the trees at all heights, and also striking the ground." Mr. Strickland suggests that these remarkable phenomena may have been occasioned by the resistance offered to the electric fluid by the unusually dry state of the earth, there having been scarcely a shower of rain since the preceding January; the electric fluid "laying piled, as it were, on the ground in masses or heaps, and finally making its escape by the roots of trees, or by projecting masses of solid rock." This peculiar form of discharge seems to be well explained by referring it to the continuous charge and discharge of *dry* air, the particles of which, as they are charged to a sufficient degree of tension, move onwards, making room for others. This form of discharge is unaccompanied by thunder; but that it is not less destructive in its effects than the more common lightning flash, appears from the following case reported by M. Regnier, in a letter to M. Merimee. (*Report of the French Academy*, August, 1846.) "A girl, eighteen or twenty years of age, was reaping with her father and mother in hot, *dry* weather, at 3 P.M. the father saw a cloud approaching, and expecting a storm to be at hand, he sent his daughter homeward, he and his wife intending to overtake her. The girl set out in a direction toward the cloud; and the father, in a few moments, turned to see what had become of her, and was surprised to see her a few paces from him lying on her face. On approaching, he found her motionless and lifeless. Three hours after the event M. Regnier accompanied the *juge de paix* to the field where the girl still lay in the position, as they told him, in which she had been found. Her arms were not forward, as occurs in ordinary falls, where time is given for this instinctive action; her dress was not raised, but her bonnet was three or four paces from her. On examining the body, there were marks as if of a burn on the right groin, and under the right arm, and there were a few drops of blood in the right ear, otherwise there were no external hurts; but the body was not opened. The conclusion arrived at was, that death was occasioned by lightning, notwithstanding the declaration of the father of the girl who affirmed that *he did not hear the slightest noise*. M. Regnier thinks that the electricity rose from the earth, because the bonnet was driven *off* and not *on*, and the marks on it resembled those which a stick with a rounded end might give when acting from below upward.

(277) A curious case is related by Professor Thomson, of Glasgow

(*Phil. Mag.* vol. xxxvii. p. 54), where two bell-wires hanging parallel to each other were *attracted*, probably by an electro-magnetic action, at the moment of the discharge of a flash of lightning down them, and compressed together with such force that it was difficult to separate them, being partially fused. The paper on the wall in the neighbourhood of the wires was stained with *oxide of copper* dispersed by the shock from the wires.

(278) Many of the extraordinary effects of lightning on buildings may, according to Peltier (*Comptes Rendus*, December 16, 1844), be understood by referring to the very unequal conducting properties of the materials which enter into their construction. He insists on the complete opposition existing between the phenomena of *static* and those of *dynamic* Electricity. When a conductor is sufficient to give a free passage to an electric discharge, we obtain nothing beyond dynamic effects, which are rendered evident by an elevation of temperature, by a vaporization of liquid, &c., but there is no indication of the attractions and repulsions that are peculiar to static Electricity. When the conductor is insufficient, the two orders of phenomena exist simultaneously; the dynamic phenomena are produced by the portion which passes through the conductor, the static by the portion arrested by its insufficiency. Now when lightning strikes a building, there are, on account of the excessively unequal conducting properties of the materials over which it passes, powerful actions of *static* Electricity. Wherever the Electricity is arrested it accumulates; and here, between the portions of the floors and the walls, for instance, powerful effects of attraction are produced, tearing up the floors and the skirting boards and destroying such furniture as may be near the moist soil and the conductor.

(279) *Lightning Conductors.*—To Franklin, whose active mind was constantly directed to practical applications of the facts disclosed by science, we are indebted for the suggestion of a method of defending buildings from the dreaded effects of lightning. His method was to erect by the side of the building to be protected a continuous metallic rod in perfect communication with the earth, and experience has fully demonstrated the value of this precaution.

In the choice of a conductor, preference should be given to copper, and it is well to divide the extremity into three or four points: it should penetrate the ground sufficiently deep to be in close contact with a stratum of moist soil, or, if possible, with a spring of water, and it should be carried above the highest point of the building. Great care should be taken that every part of the rod be *perfectly continuous*, and that its substance be sufficient to prevent

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any chance of its being melted: perfect security on this head is arrived at by employing a copper rod of one inch in diameter. The conductor should be applied as closely as possible to the walls of the building, and all contiguous masses of metal, such as gutters, water-pipes, &c., should be metallically connected with it. "The practice of insulating the conductor," observes Sir William Harris (*Nature of Thunder-storms*, p. 128), "by means of pitch, glass, or some bad conducting substance, or otherwise to apply it at a short distance from the walls so as to interpose a stratum of air between it and the building, is not only useless, but disadvantageous, and implies a distrust of the principles upon which the conductor is founded." Numerous carefully conducted experiments have proved that an electrical discharge never leaves an easy line of transit in order to pass upon matters out of that line; but if it should, it can scarcely be imagined that a lightning flash that can break through several hundred yards, and shiver into fragments the most compact bodies, would be arrested in its course by a few inches of any solid insulating substance, or by a few feet of air. Equally inconsistent with the principles of electrical science is the practice not unfrequently adopted of placing balls of glass on the projecting points of buildings, under the impression that glass being a non-conductor of Electricity, it would divert the lightning from the building. Christ Church, at Doncaster, was thus "protected" till it was struck by a flash of lightning, and nearly demolished. On the other hand, a well arranged lightning-conductor does not *invite* the lightning any more than a rain-pipe attracts the rain which falls on a building during a shower. Its action is purely passive: it offers to the disruptive discharge a line of small resistance, whereby those irresistible mechanical effects which attend the passage of the discharge through resisting matter are prevented. A conductor erected with the precautions above described was considered by the French philosophers (*Annales de Chimie et de Physique*, vol. xxvi.) adequate to protect a circular space of a radius double its height above the highest point of the building to which it is attached. A case is, however, related by Loomis (*American Journal of Science*, 1850, p. 320), in which a conductor constructed according to this rule failed to protect entirely the building, and he thinks it unsafe to rely upon a rod to protect a circle whose radius is more than once and a half the height of the rod.

A building with a metallic roof is protected in a very simple manner. The roof should be connected by straps of copper, with the metallic gutters which carry off the rain-water, and rods, projecting fifteen or twenty inches from the tops of the chimneys, should like-

wise be soldered to the roof. The lightning being transmitted principally along the *surface* of a conductor, an ordinary sized metallic gutter will conduct silently the most violent discharge that may fall from the clouds.

(280) The great importance of attending to the conducting condition of the ground in which the end of the conductor is fixed, and of securing an efficient discharging train, is exemplified in the following account of mischief done by a flash of lightning to a house *furnished* with a lightning conductor, communicated by M. de Carville to the French Academy of Sciences, January 19th, 1846 (*Elect. Mag.*, vol. ii. p. 314).

"On the morning of Dec. 20, 1845, during a heavy hail shower, a fire-ball was seen to bifurcate in the vertical of the lightning conductor, placed at the centre of the chateau of Boisyvon near Vire, 9·1 metres in length above the top of the roof. The electric fluid immediately produced great havoc on both sides of the chateau, at 9 metres distant from the conductor. In the points where the Electricity reached the earth, several persons perceived as it were a large tube of fire rolling on the ground. The conductor of the lightning rod descends into the ground by a drain, 0·11 metres square at the surface of the said ground, and 0·20 metres at the moment where it enlarges, and forms a *walled reservoir of about a metre in diameter.* The whole was filled with carbon. A *walled reservoir* speaks volumes."

(281) When large ranges of straggling buildings are to be protected, two or more conductors should be applied, and the whole connected together by bands of metal, and Sir W. Harris recommends that the conductors should be constructed of copper pipe from one to two inches in diameter, and about one fifth of an inch thick. It may be prepared in lengths of about 10 feet, and be united together at the line of fixing, by screwing the lengths together upon short intermediate pieces.

The above is by no means a solitary instance of a building being struck and damaged by lightning, though armed with a pointed conductor. On the 17th of June, 1781, the poor house at Heckingham sustained injury though furnished with no less than eight conductors (*Phil. Trans.* vol. lxxii. p. 377). On the 12th of May, 1777, (*Phil. Trans.*) the board-house at Purfleet was struck and damaged; in February, 1829 (*Annales de Chimie*, t. xl. p. 391), a magazine of powder was struck, and injured at Bayonne, though provided with a lightning rod, projecting about twenty feet above the building, and on the 14th of August, 1779, the church of "*Notre Dame de la Garde*," at Genoa, was struck and damaged, a conductor having been applied to it in the preceding year (*Sammlungen zur Physik* for 1782, vol.

ii., p. 588). But in these, as in many other instances that might be quoted, the conductors appear to have discharged their duty most efficiently, conveying away in safety the great mass of the explosion, while the small amount of damage that was in each case sustained was occasioned by the lightning having *bifurcated*, or *bifurcated before* it struck the buildings, one portion having passed down the conductors whilst other portions fell on points far distant, and they illustrate the importance of securing into one general system of conduction all those parts of the building situated at a distance from the rod.

(282) The lightning conductor applied to the Nelson Monument in Trafalgar Square, is arranged with all the conditions requisite for a perfect defence. The plates of copper are three inches wide and one-fifth of an inch thick, led in two lines across the adjacent fillets of the flutes of the column, and applied in lengths of ten feet, united by dovetailing. The whole is pinned to the masonry by copper nails secured with lead. The conducting plates are united to the ornamental bronze work surrounding the capital, which is again connected with bands of metal, traversing the back and sword of the figure, and ending in two points, one at the aigrette of the hat, the other at the extremity of the sword; at the pedestal the two separate lines of metal unite with a plate six inches wide, carried on near the north-east angle to the earth where it is connected with three pointed branches under the surface of the ground.

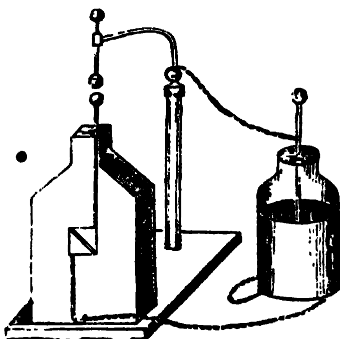
(283) The conductor of the Monument may likewise be referred to as illustrating the conditions for perfect protection. This beautiful column is terminated by a metallic vase four or five feet in diameter, surrounded by pointed metallic plates, representing flames of fire: between this and the floor of the gallery, are four thick bars of iron supporting a set of iron steps. One of these bars, an inch thick and five inches wide, is connected with the iron rail of the staircase which reaches to the bottom of the building (*Phil. Trans.* vol. lxiv. p. 389). The whole height of this structure, including the one at its summit, is 202 feet; it has never yet been damaged by lightning.

(284) When the electrical explosion falling on the conductor is very dense, the rod sometimes becomes covered with a luminous glow, and a loud whizzing sound is at the same time heard. This luminous appearance is however of a perfectly harmless character, and, provided the conductor be of sufficient capacity, it is unattended with any calorific effect: it appears to be a sort of glow discharge, (135) between metal and air immediately in the points of contact, and may be classed with the phosphorescent flashes attendant on the aurora borealis, or with the streaming of ordinary Electricity in

the exhausted receiver of an air pump. The question, whether or not danger is to be apprehended from "lateral discharges," thrown off by a conductor whilst conveying an electrical explosion, was long and minutely discussed some years ago. The question was indeed a most serious one, and if answered in the affirmative, it would be subversive of the use of lightning conductors altogether; for if by our insignificant arrangements, we can obtain a lateral discharge of sufficient intensity to ignite gases and to communicate shocks, the effects of similar explosions from a conductor conveying a flash of lightning some hundreds of yards in length must be irresistible. We have already (197) considered the nature of the so called lateral discharge in ordinary Electricity; and that the phenomena do not obtain with lightning conductors may be considered as established by the experience of nearly a century, during which time there is no instance on record of a lightning conductor, properly arranged, throwing off lateral explosions to any semi-insulated metallic masses near it; but that the discharge may in its course *divide* between the rod and metallic bodies in good connection with the earth is very possible, and illustrates the importance of uniting all such metallic circuits with the lightning rod, and thereby avoiding all danger of a destructive explosion.

(285) The little arrangement Fig. 120, amusingly illustrates the use of a continuous conductor. A board about three quarters of an inch thick, and shaped like the gable end of a house, is fixed perpendicularly upon another board, upon which a glass pillar also is fixed in a hole about eight inches distant from the gable-shaped board. A small hole, about a quarter of an inch deep, and nearly an inch wide, is cut in the gable shaped board, and this is filled with a square piece of wood of nearly the same dimensions. It should be *nearly* of the same dimensions, because it must go so easily into the hole, that it may drop off by the least shaking of the instrument. A brass wire is fastened diagonally to this square piece of wood, and another of the same dimensions, terminated by a brass ball, is fastened on the gable-shaped board, both above and below the hole. From the upper extremity of the glass pillar a crooked wire proceeds, terminated also by a brass ball, and sufficiently long to reach immediately over the ball or the wire of the

Fig. 120.



board. The glass pillar is loosely fixed in the bottom board, so that it may move easily round the axis. It is evident that, with this arrangement, a shock from a Leyden jar may easily be sent over the square hole by connecting the exterior coating with the wire in the gable-shaped board below it, and the interior with the wire on the glass pillar which comes within the striking distance of the wire in the gable-shaped board below it.

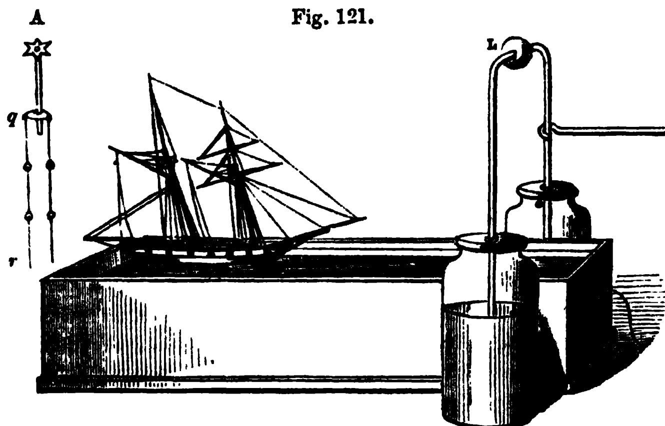
Suppose now the square piece of wood to be placed in the hole in such a manner that the wire attached to it diagonally shall be in *contact* with the wires above and below it, a shock may evidently be transmitted without any disturbance taking place; but if it be put into the hole in an *opposite* direction, so that the shock from the jar shall be obliged to pass over it altogether in the form of a spark in its passage from wire to wire, the concussion it will occasion will throw the square piece of wood to a considerable distance from the apparatus. The square piece of wood may here be supposed to represent a window, and the wire a continuous or broken conductor passing by the side of it, and the violent effects produced by the minute quantity of Electricity accumulated in a Leyden jar may be considered as a humble imitation of the effects of a stroke of lightning. When the passage is uninterrupted, the Electricity passes quietly down, but when impeded it produces the most violent effects.

(286) To exemplify the method of defending ships, a small model may be made, with a glass tube for the mast. Into this tube two wires are to be inserted through its opposite ends, until within half an inch of each other. The tube is then to be filled with water, and the ends stopped. Connect the lower wire with a small metallic thread tied to the stern. The upper wire is to be surmounted by a brass ball. A moveable conductor may be formed of a thin copper wire, placed parallel with, and rising above the mast: this wire is to be connected at the bottom with the metal thread. If a powerful charge be passed along the mast when the conductor is attached no effect is produced; but if the conductor be removed the mast is shattered to pieces.

The apparatus shown in Fig. 119 (Cuthbertson's *Practical Electricity*, p. 83), illustrates the same in an amusing manner. The trough is filled with water till the ship swims in it, and so that when it sails exactly under the ball L, the top of the mast may nearly touch it. By means of a thread attached to the head of the ship, it may be drawn quickly between the charged Leyden jars, at the opposite end of the trough. The moment the mast comes within striking distance of the ball L discharge takes place, and the mast falls into the water in pieces. When the mast is repaired and set

up again, hang the chain q r from the top of the spindle, the ends dropping into the water, and screw upon the top of the spindle the

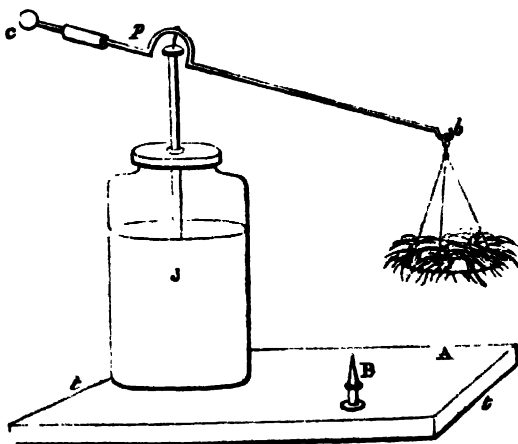
Fig. 121.



star A, then charge the jars, and on drawing the vessel as before, underneath the ball L, it will be struck, but no damage will be done to the mast, and the fire will be seen to pass along the chain without touching it. If the ship be drawn slowly underneath the ball, the discharge will take place silently, because of the points on the top of the spindle.

(287) The following very instructive experiment was arranged by Harris (*Nature of Thunder-storms*, p. 188), with the view of illus-

Fig. 122.



trating the power of pointed bodies to discharge the Electricity of the clouds *without attracting them*. It is a modification of an old

experiment of Franklin's (*Letters*, p. 121). *c p b* is a long bent arm of light, brass wire, balanced by means of a central point *p* on the charging rod of the jar J, and on which it has free motion in all directions; A is a light disc of gilded wood, resembling a common scale pan, covered with a lock of fine cotton wool, and suspended by conducting threads from the arm *c p b*, a pointed body B is placed on the same conducting base as the jar. If the jar be now charged, the cotton in the scale-pan will begin to extend its filaments, and the whole will be attracted towards the table much in the same way as a cloud appears to be attracted towards the earth, causing the bent arm *c p b* to assume an inclined position. If the arm be now caused to move upon its centre *p*, so as to allow the artificial cloud A to approach the point B, the arm will gradually assume its previous horizontal position, in consequence of the influence of the point in neutralizing the opposite forces. As the artificial cloud continues to approach the point, this action proceeds so rapidly as frequently to produce a whizzing sound, the bent arm recovering at the same time its horizontal position. The scale-pan A, so far from being attracted by the point, actually recedes from it, and very faithfully represents the nature of the operation of pointed bodies on charged clouds.

(288) Ships, particularly in tropical climates, are especially exposed to danger from lightning, and although the amount of damage done in the British navy has been immense, it was not till the year 1842 that an efficient system of permanent conductors on the plan recommended by Sir William Snow Harris was established. Conductors had, indeed, been used for many years previously, but they consisted of chains or links of copper about the size of a goose quill, and were generally packed away in a box, where they frequently remained untouched during long and hazardous voyages. Mr. Singer appears to have been the first Electrician who recommended that fixed conductors should be employed, but their final introduction and general use has at length, after nearly twenty-five years' unceasing labour, been effected by Harris. His original proposition (*Nautical Magazine*, 1852) was to complete the conducting power of the masts by incorporating with them a series of copper plates of given and capacious dimensions, from the truck to the keelson, so mechanically arranged and combined in two laminæ as to yield freely to any flexure or strain, to which the spars might be subject, at the same time preserving an efficient and unbroken chain, and then to connect these vertical conducting lines by conducting plates similarly arranged with the various metallic bolts passing through the keelson and other parts of the hull to the copper expanded over the bottom; thus uniting, as it were, into one great chain, the conductors on the masts,

the metallic bodies in the hull, and the general surface of the sea, so that from the moment of lightning falling on any point aloft, the explosive action would cease, and the general fabric be insured against further damage. The object being to bring the general fabric into that passive or non-resisting state it would assume, supposing the whole structure were metallic throughout, or as nearly so as possible. By this arrangement the conductors are always in their place, always ready to meet the most unexpected danger, and whilst clear of the rigging, and admitting of every possible motion of the masts, they also admit of any part of the mast being removed. They are also independent of the crew, who are not required to touch them, and they prevent a flash of lightning from falling on the ship, or on any given point, or from entering upon any circuit or course of which they do not form a part.

(289) The practical application of this system of conductors was attended with considerable difficulty, but the conditions of flexibility and continuity were at length provided for by constructing the wires of narrow plates of copper sheet in lengths of four feet, placed in two layers, one immediately over the other, and in such a way as to allow the butts or joints of the one series to fall immediately under or over the continuous portions of the other, the series or joints being riveted to the butts throughout the line. We have thus an alternating series of sheet joints producing a perfectly continuous and perfect line of conduction. The conducting wires thus arranged had now to be incorporated with the spars, led throughout the hull, and connected in various directions with the copper expanded over the bottom of the ship, and with the sea. The incorporation with the spars presented some difficulty, which was finally overcome by laying the plates in shallow grooves cut for their reception along the *aft* sides of the respective masts, from the truck to the keelson, and preserving an adequate connection in the caps through which the upper portions of the masts were required to slide. The plates were fixed with strong copper nails. In Figs. 123, 124, the conductor is shown by the dotted line A B C D, and it will be seen that any elongation or contraction of the masts, or the removal of either of them, in no way disturbs the continuity of the line, which evidently remains the same, and is the shortest and best conducting line between the mast head at D and the sea at S. When the sliding masts are struck, a part of the conducting line necessarily remains below the cap and top; but as this is quite out of the circuit, it will not at all influence the passage of the electric fluid along the shorter line, as Sir William has proved by direct experiment.

(290) The absolute security ensured to vessels by this system of

Fig. 123.

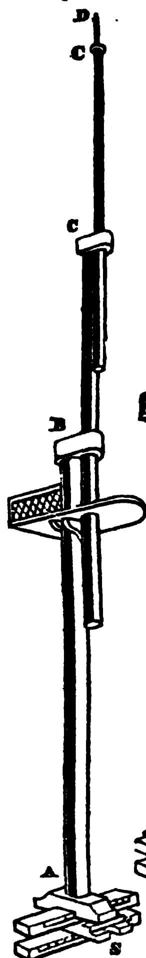


Fig. 124.



lightning conductors, is conclusively demonstrated by the following analysis of recorded cases of "Ships struck with lightning," published by Sir W. Harris in the *Nautical Magazine* (1852). The general system of lightning conductors has been more or less in use since the year 1830, at first in about 10 of H.M. ships, and since 1842 throughout the whole navy, which gives a clear course of experiments of at least 20 years. Now during this time the ships having the new conductors have been exposed to lightning in its most appalling forms, in almost every part of the world, and during these 20 years there are not more than 40 recorded cases of ships struck by lightning though numbers of remarkable instances in which the conductors have carried off, tranquilly as it were, large streams of atmospheric Electricity. *In no case has any ill consequence ensued.* Between 1822 and 1842, that is up to the date at which the system was fully adapted, and including ten years common to both periods, there are 60 recorded cases of ships struck, and in *every instance destructive damage ensued, and in many cases to a frightful extent.* It thus appears that ships, *not* furnished with the new conductors, have been struck by lightning more frequently than ships having such conductors, in the proportions of 3·: 2, a result quite conclusive of the question, "whether such conductors operate in attracting lightning to the ship." In short, since the general introduction of this system into the public service, *damage by lightning has vanished altogether from the records of the navy.*

(291) Volcanic eruptions in the sea are generally attended by thunder and lightning, and may be classed among electrical phenomena. In June, 1811, Captain Tilland observed off the island of St. Michael one of these marine volcanoes, of which he has given the following account in the *Philosophical Transactions.* "Imagine," says he, "an immense body of smoke rising from the sea, the surface

of which was marked by the silver rippling of the waves occasioned by the slight and steady breezes incidental to those climates in summer. In a quiescent state, it had the appearance of a circular cloud, revolving on the water like a horizontal wheel, in various and irregular involutions, expanding itself gradually on the lee side, when suddenly a column of the blackest cinders, ashes, and stones, would shoot up in the form of a spire, rapidly succeeded by others, each acquiring greater velocity, and breaking into various branches resembling a group of pines; these again forming themselves into festoons of white feathery smoke. During these bursts, the most vivid flashes of lightning continually issued from the densest part of the volcano, and the columns rolled off in large masses of fleecy clouds, gradually expanding themselves before the wind, in a direction nearly horizontal, and drawing up a quantity of waterspouts, which formed a striking addition to the scene. In less than an hour, a peak was visible, and in three hours from the time of our arrival, the volcano, then being four hours old, a crater was formed twenty feet high, and from four to five hundred feet in diameter. The eruptions were attended by a noise like the firing of cannon and musketry mixed; as also with shocks of earthquakes, sufficient to throw down a large part of the cliff on which we stood. I afterwards visited the volcanic island: it was eighty yards high, its crater upon the level of the sea was full of boiling water; it was about a *mile* in circumference, and composed of porous cinders and masses of stone."

(292) It has been a subject of discussion among philosophers whether those destructive meteors called *tornadoes*, are really electrical phenomena, or whether they are caused by heat evolved from condensing vapour. The subject came under the investigation of the French Academy of Sciences, in 1839, in consequence of a demand for indemnity for the devastation caused by a tornado at Chatenay near Paris, under a contract of insurance against thunder-storms. The question was referred to Arago the president of the Academy, and under his auspices a report was made by Peltier agreeably to which the insurers were called upon to pay. The following extract from this report will convey some idea of the devastating effects of this remarkable meteor. "Up to this time there had been thunder continually rumbling within the second thunder cloud, when suddenly an under portion of this cloud descending and entering into communication with the earth, the thunder ceased. A prodigious attractive force was exerted forthwith, all the dust and other light bodies which covered the surface of the earth mounted towards the apex of the cone formed by the cloud, a rumbling thunder was continually heard. Small clouds wheeled about the invested cone, rising and descending with rapidity. The column was terminated by a cap of fire. To

the south-east of the tornado, on the side exposed to it, the trees were shattered, while those on the other side of it preserved their sap and verdure ..... finally it advanced to the park and castle of Chatenay, overthrowing everything in its path. On entering this park, which is at the summit of a hill, it desolated one of the most agreeable residences in the neighbourhood of Paris. All the finest trees were uprooted, the youngest only, which were *without* the tornado, having escaped. The walls were thrown down, the roofs and chimneys of the castle and farm house carried away, and branches, tiles, and other moveable bodies, were thrown to a distance of more than five hundred yards. Descending the hill towards the north, the tornado stopped over a pond, killed the fish, overthrew the trees, withering their leaves, and then proceeded slowly along an avenue of willows, the roots of which entered the water, and being during this part of its progress much diminished in size and force, it proceeded slowly over a plain, and finally, at a distance of more than a thousand yards from Chatenay divided into two parts, one of which disappeared in the clouds, the other in the ground." The following is the explanation offered by Peltier. "In contemplating the rise and progress of this phenomenon we see the conversion of an ordinary thunder gust into a tornado; we behold two masses of clouds exposed to each other, of which the upper one, in consequence of the repulsion of the similar Electricities with which both are charged, repelling the lower towards the ground, the clouds of the latter descending and communicating with the earth by clouds of dust, and by the trees. This communication being once formed, the thunder immediately ceases, and the discharges of Electricity take place by means of the clouds, which have thus descended, and the trees. These trees traversed by the Electricity, have their temperature in consequence raised to such a point that their sap is vaporized, and their fibres sundered by its efforts to escape. Flashes, and fiery balls, and sparks accompanying the tornado: a smell of sulphur remains for several days in the houses, in which the curtains are found discoloured. Everything proves that the tornado is nothing else than a conductor formed of the clouds, which serves as a passage for a continual discharge of Electricity from those above, and that the difference between an ordinary thunder-storm, and one accompanied by a tornado, consists in the presence of a conductor of clouds, which seem to maintain the combat between the upper portion of the tornado and the ground beneath."

(293) Notwithstanding this report, it appears that in 1841* the Academy signed another report sanctioning the idea originating with

* See a pamphlet by Dr. Hare, of Philadelphia, entitled, "Exposure of the Errors and Inconsistencies of the French Academicians respecting Tornadoes."

Professor Espy, that tornadoes are caused by the heat imparted to an ascending column of air by condensing vapour, Electricity occasionally intervening, but not being in the least essential to the generation or endurance of the meteor. It was assumed by Espy that the rise of temperature thus caused would create a buoyancy like that of a balloon, and an upward force, and so great an acceleration as to produce the phenomena of a tornado at the foot of the column affected.

Dr. Hare adopts, and, indeed, *originated* (*Experimental Observations*, 1836) the electrical hypothesis, but he thinks that the idea of Peltier, that the cloud acts as a *conductor*, is untenable. He is of opinion that a tornado is the effect of an electrified current of air superseding the more usual means of discharge between the earth and the clouds in those sparks or flashes which we call lightning, and that it bears the same relative position to lightning that the carrying or *convective* discharge does to the electrical spark; and with this explanation the phenomena at Chatenay, as well as those observed in 1836 by Dr. Hare himself on visiting the scene of a tornado at New Brunswick, appear well to accord.

(294) In the *Comptes Rendus* (Oct. 21, 1844), there is a report of the phenomena attending a dry *trombe*, or tornado, which occurred at Escalqueus. It appeared in the form of a vast inverted cone, and was manifested in incessant rapid rotation. Suddenly it seized upon a field of maize, which it dispersed in all directions. It completely demolished a farm-house, killing all the poultry. It carried up, threw down, and took up again several times a youth of thirteen or fourteen years of age, without, however, doing him any serious damage. It then passed on to another farm, about two miles distant from the former, carrying off the roofs of the houses in its course. A continual dead and terrifying noise was heard by all who witnessed it, and those who were in the midst of it saw fire. In fact, the insurance company were quite ready to admit against their own interests, that the mischief done was the effect of lightning.

(295) The following fearful account of the ravages committed by a waterspout at Cette, extracted from a French paper, appeared in the "Times" of October 30, 1844. "A frightful misfortune has this afternoon plunged our whole population into a state of consternation and despair. About four o'clock an electric waterspout fell upon our town, and committed such ravages, that at the present moment it might be supposed that the town had been submitted to all the horrors of a siege. This terrible phenomenon, which arrived in the direction of the fortress of St. Pierre, skirted the mole in its whole length; and when it came opposite the engineers' establishment,

attracted probably by the conductor and the zinc roof of the house, it turned round the edifice, and at last fell with violence upon it. At the same moment a violent explosion was heard, and the whole population thought that its last hour was come. During two minutes' space of time a terrific crash resounded in the air. The roofs of the houses were smashed to pieces, and the fragments were carried to the most distant part of the town. The building belonging to the engineers has been entirely sacked; its zinc roof was carried off in the twinkling of an eye, and the whole façade demolished and razed to the ground, so that nothing now remains of it but the back and side walls. Another house, four stories high, new, and solidly built, was literally crushed to the earth. In every apartment the separation walls were destroyed, and the windows torn out; everywhere destructive traces have been left. A fearful inundation joined at the same time its ravages to those of the electric waterspout. In an instant the waters of the canal rose and flooded the quays. At least a dozen boats were sunk in the canal itself, and many persons perished. Five or six large vessels have been completely wrecked, and remain with their keels uppermost. In the streets and on the quays are everywhere to be seen wounded wretches, some with bloody heads, others with mutilated limbs. It is impossible to give any description of the feelings of terror produced in the minds of the whole population."

(296) The effects here described are considered by Peltier as completely inexplicable on the theory of whirls produced by the meeting of contrary winds. Arago has also admitted that they cannot be understood without the aid of Electricity. The following are the consequences deduced by Peltier from his investigations into the subject.

1°. All the immediate phenomena observed in waterspouts are due to Electricity. They are the results of secondary phenomena, which almost always accompany them. The latter vary with the locality and the state of the atmosphere.

2°. Their general effects are due either to statical or dynamical Electricity: more generally they proceed from both.

3°. The statical effects are phenomena of attraction and repulsion.

4°. The attraction of an electrical cloud is accompanied by a rush of air towards this cloud, from whence result currents directed from the exterior to the interior, and proceeding from all surrounding points. It is manifested also by the projection of the vapour of water, of liquid water itself, and of bodies that it raises or tears according to the force with which it acts.

5°. The progress of its attractive power is plainly marked both on

sea and land. On sea it appears by the boiling of the waters, and the smoky appearance which is raised from them. On land its course is rendered manifest by its effects upon the air, the ground, and all loose bodies which it encounters.

6°. The attraction of the clouds is also manifest by the greatly increased evaporation of the waters, and the consequent fall of their temperature. The repulsion is manifested by currents of air which issue from the electric cloud, and only exist in its neighbourhood; at a little distance from it a dead calm prevails. These double currents undergo various modifications produced by the localities and the various qualities of the ground.

7°. The repulsion is also manifested by the cone which is formed in the sea, in the very centre of the smoky vapours, an effect which can be easily reproduced experimentally.

8°. If an inductive action take place between two clouds charged with opposite electricities placed at a certain distance asunder, a portion of their vapour will resume the state of common vapour; this will lower the temperature of neighbouring parts, which may descend even below the freezing point; then the vapour of water crystallizes in snowy flakes, which act immediately after their formation, like other light bodies. The portion thus transformed into snow, and which is charged with the Electricity of the inferior cloud, is attracted by the superior cloud, then there is a neutralization of Electricity, a fall of temperature, and so on.

9°. Finally, the electrical tension of the superior cloud facilitates the evaporation of the liquid which moistens the snowy globule or which already covers the ice. The electrified clouds acting by induction upon the ground are attracted to it. The clouds thus approach the earth in a greater or less quantity, depending on the energy of the attraction and their specific gravity.

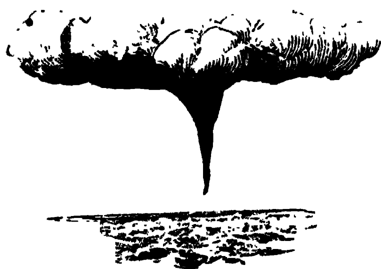
The sound which sometimes accompanies the tornado Peltier ascribes to a number of small partial explosions, which take place between the cloud and the ground. They are louder in the case of waterspouts which traverse the land, because of the badness of the conductors presented to them; they lose their intensity over the sea because water is a better conductor. In short, there is nothing but Electricity, and Electricity of prodigious tension, which can produce effects so violent, within limits so very confined, while leaving the surrounding places calm.

(297) That which renders the *waterspout* so remarkable is the circumstance of a double cone being formed when the phenomenon is complete, one cone pointing downwards from a cloud, whilst another points upwards from the sea. Captain Beechey, in the

published account of his voyage in the Pacific when he commanded the "Blossom," gives the following description of a waterspout which nearly overwhelmed the vessel. "It approached amidst heavy rain, thunder, and lightning, and was not seen until it was very near the ship. The wind blew with great violence, momentarily changing its direction, as if it were sweeping round in short spirals; the rain, which fell in torrents, was also precipitated in curves, with short intervals of cessation. Amidst this thick shower the waterspout was discovered extending in a lapwing form from a dense stratum of cloud to within thirty feet of the water, where it was hid by the foam of the sea, being whirled upwards by a tremendous gyration. It changed its direction after it was first seen, and threatened to pass over the ship, but being diverted from its course by a heavy gust of wind, it gradually receded. On the dispersion of this magnificent phenomenon, we observed the column to diminish gradually, and at length retire from the cloud from which it had descended in an undulating form .... *A ball of fire* was observed to be precipitated into the sea, and there was much lightning. The column of the waterspout first descended in a spiral form, until it met the ascending column a short distance from the sea. A second and a third were afterwards formed, which subsequently united into one large column, and this again separated into three small spirals, and then dispersed. The barometer was not affected, but the thermometer fell eight degrees. The gyrations were in a direction contrary to that of the hands of a watch."

(298) Another waterspout, seen by Captain Beechey in lat. 20° N. and long. 22° W., was thus described and illustrated by him in a letter to Colonel Reid (*Law of Storms*, p. 400): "The day had been very sultry, and in the afternoon a long arch of heavy cumuli and nimbi rose slowly above the southern horizon: while watching its movement, a waterspout began to form at a spot on the underneath side of the arch, that was darker than the rest of the line. A thin cone (Fig. 125) first appeared, which gradually became elongated,

Fig. 125.



and was shortly joined with several others, which went on increasing in length and bulk until the columns had reached about half down to the horizon. They here united and formed one immense dark coloured tube. The sea beneath had hitherto been undisturbed, but when the columns united it became per-

ceptibly agitated, and was almost immediately whirled in the air with a rapid gyration, and formed a vast basin, from the centre of which the gradually lengthening column seemed to drink fresh supplies of water, Fig. 126. The column had extended about two-thirds of the way towards the sea, and nearly connected itself with the basin, when a heavy shower of rain fell from the right of the arch at a short distance from the spout, and shortly after another fell from the opposite side. This discharge appeared to have an effect upon the waterspout, which now began to retire. The sea, on the contrary, was perceptibly more agitated, and for several minutes the basin continued to increase in size, although the column was considerably diminished. (Fig. 127.) In a few minutes more the column had entirely disappeared, the sea, however, still continued agitated, and did not subside for three minutes after all disturbing causes from above had vanished. This phenomenon was unaccompanied by thunder or lightning, although the showers of rain which fell so suddenly seemed to be occasioned by some such disturbance. Two days afterwards we got into the south-east trade-wind in lat. 0° 33′ S. and long. 21° 40′ W."

Fig. 126.



Fig. 127.



(299) That magnificent meteorological phenomenon, the *aurora borealis*, is by many supposed to be in some way connected with Electricity, and its appearance may be imitated with great exactness by passing a stream of Electricity from the conductor of a machine through a tube partially exhausted of air. The same variety of colour and intensity, the same undulating motions and occasional coruscations, and the same inequality in the luminous appearance are exhibited as in the aurora, and when the rarefaction is considerable various parts of the stream assume that peculiar glowing colour

which occasionally appears in the atmosphere, and which is regarded by the uninformed observer with astonishment and fear. The experiment is modified by De la Rive thus (*Comptes Rendus*, *Oct.* 15, 1849). A cylindrical rod of iron is cemented air-tight into a glass globe. It is covered, except at its two ends, with an insulating and thick layer of wax. A copper ring surrounds the bar above the insulating layer in its internal part the nearest to the side of the globe: from this ring proceeds a conducting-rod, which, carefully insulated, traverses the same tubulure as the iron bar, but without communicating with it, and terminates externally in a knob or hook. The air being rarefied through a stop-cock attached to a second tubulure, the hook or knob is made to communicate with one conductor, and the external extremity of the iron bar with the other conductor of a machine: the Electricities unite in the globe, forming a more or less regular fascicle of light. On bringing the external end of the iron bar into contact with a pole of an electro-magnet, taking care to preserve good insulation, the light becomes a luminous ring, which *rotates round the bar* in a direction regulated by the magnetization of the bar. From this luminous ring brilliant jets issue, and form the fascicle. On removing the electro-magnet these phenomena cease, giving place to the previous appearance, and what is generally known by the name of the *electrical egg*.

(300) The aurora borealis is seldom seen in perfection in this country, and of late years has rarely been noticed at all, but Captain Parry, in his second voyage for the discovery of a north-west passage, had abundant opportunities of observing it in the greatest splendour. That highly distinguished philosopher and chemist, Dr. Dalton, has also furnished us (*Meteorological Essays*) with the following account of an aurora seen by him on the 15th of October, 1792.

"Attention was first excited by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by at eight o'clock in the evening, though there was no moon nor light in the north. From half-past nine to ten, there was a large, luminous, horizontal arch to the southward, and several faint concentric arches northward. It was particularly noticed that all the arches seemed exactly bisected by the plane of the magnetic meridian. At half-past ten o'clock streamers appeared, very low in the south-east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity; when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as surpasses all description. The intensity of the light, the prodigious number and volatility of the beams, the grand intermixture of all the prismatic colours in their

utmost splendour, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time, the most pleasing and sublime spectacle in nature. Every one gazed with astonishment, but the uncommon grandeur of the scene only lasted *one minute;* the variety of colours disappeared, and the beams lost their lateral motion, and were converted into the flashing radiations.

"Notwithstanding the suddenness of the effulgence, at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another. These rows were situated before each other with the exactest order, so that the base of each row formed a circle, crossing the magnetic meridian at right angles; and the several circles rose one above another, so that those near the zenith appeared more distant from each other than those near the horizon, a certain indication that the real distances of the rows were nearly the same. The aurora continued for several hours. There were many meteors (falling stars, as they are commonly called) seen at the same time; but they appeared to be below, and unconnected with the aurora."

(301) "The aurora," says Captain Parry, "began to show itself as soon as it was dark. Innumerable streams of white and yellowish light occupied the heavens to the southward of the zenith, being much brighter in the south-east, from which it often seemed to emanate. Some of these streams were in right lines, others crooked, and waving in all sorts of irregular figures, moving with inconceivable rapidity in various directions. Among them might frequently be observed shorter bundles of rays, which, moving even with greater velocity than the rest, have acquired the name of 'merry dancers.' In a short time the aurora extended itself over the zenith, about half way down to the northern horizon, but no further, as if there were something in that quarter of the heavens that it did not dare to approach. About this time, however, some long streamers shot up from the horizon in the north-west, but soon disappeared. While the light extended over part of the northern heavens, there were a number of rays assuming a circular or radiated form, near the zenith, and appearing to have a common centre near that point, from which they all diverged. The light of which these were composed appeared to have inconceivably rapid motion in itself, though the form it assumed, and the station it occupied in the heavens, underwent little or no change for perhaps a minute or more. This effect is a common one with the aurora, and puts one in mind, as far as its motion alone

is concerned, of a person holding a long ribbon by one end, and giving it an undulatory motion through its whole length, though its general position remains the same. When the streams or bands were crooked, the convolutions took place indifferently in all directions. The aurora did not continue long to the north of the zenith, but remained as high as that point for more than an hour. After which, on the moon rising, it became more and more faint, and at half-past eleven was no longer visible.

"The colour of the light was most frequently yellowish white, sometimes greenish, and once or twice a lilac tinge was remarked, when several strata appeared as it were to overlay each other by very rapidly meeting, in which case the light was always increased in intensity. The electrometer was tried several times, and two compasses exposed on the ice during the continuance of this aurora, but neither was perceptibly affected by it. We listened attentively for any noise that might accompany it, but could hear none; but it was too cold to keep the ears uncovered very long at one time. The intensity of the light was something greater than that of the moon in her quarters. Of its dimming the stars there cannot be a doubt. We remarked it to be in this respect like drawing a gauze veil over the heavens in that part, the veil being most thick when two of the luminous sheets met and overlapped. The phenomenon had all the appearance of being full as near as many of the clouds commonly seen, but there were none of the latter to compare them with at the time."

(302) The commencement and successive phases of a complete aurora have been thus graphically described by Humboldt (*Cosmos, Sabine's translation*, vol. i. p. 180): "Low down on the horizon, about the part where it is intersected by the magnetic meridian, the sky, which was previously clear, is darkened by an appearance resembling a dense bank or haze, which gradually rises, and attains a height of eight or ten degrees. The colour of the segment passes into brown or violet, and stars are visible through it, as in a part of the sky obscured by thick smoke. A broad luminous arch, first white, then yellow, bounds the dark segment; but as the bright arch does not appear until after the segment, Argelauder considers that the latter cannot be attributed to the mere effect of contrast with its bright margin. The azimuth of the highest point of the luminous arch, when carefully measured, has been usually found not quite in the magnetic meridian, but from five to eighteen degrees from it, on the side towards which the magnetic declination of the place is directed. In high northern latitudes, in the near vicinity of the magnetic pole, the dark segment appears less dark, and sometimes is

not seen at all; and in the same localities, where the horizontal magnetic force is weakest, the middle of the luminous arch deviates most widely from the magnetic meridian. The luminous arch undergoes frequent fluctuations of form: it remains sometimes for hours before rays and streamers are seen to shoot from it, and rise to the zenith. The more intense the discharges of the aurora, the more vivid is the play of colours, from violet and bluish white through gradations to green and crimson. In the common Electricity excited by friction it is also found that the spark becomes coloured only when a violent explosion follows high tension. At one moment the magnetic streamers rise singly, and are even interspersed with dark rays resembling dense smoke; at another they shoot upwards simultaneously from many and opposite points of the horizon, and unite in a quivering sea of flame, the splendour of which no description can reach, for every instant its bright waves assume new forms. The intensity of this light is sometimes so great, that Lowenorn (29th January, 1786) discerned its coruscations during bright sunshine. Motion increases the visibility of the phenomenon. The rays finally cluster round the point in the sky corresponding to the direction of the dipping needle, and there form what is called the corona—a canopy of light of milder radiance, streaming, but no longer undulating. It is only in rare cases that the phenomenon proceeds so far as the complete formation of the corona; but whenever this takes place the display is terminated. The streamers now become fewer, shorter, and less intensely coloured; the corona and the luminous arches break up, and soon nothing is seen but irregularly scattered, broad, pale shining patches of an ashy grey colour, and even these vanish before the trace of the original dark segment has disappeared from the horizon. The last trace that remains of the whole spectacle is often merely a white delicate cloud, feathered at the edges, or broken up into small round masses like cirro-cumuli."

The following is a general description of the aurora as observed by M. Lottin, at Bossekop, in the bay of Alten, on the coast of West Finland, in lat. 70 N., during the winter of 1838—9. (*Becquerel's Traité de Météorologie.*) "Between the hours of four and six in the afternoon the sea-fog, which constantly prevails in those regions, becomes coloured on its upper border, or rather is fringed with the light of the aurora, which is behind it. This border becomes gradually more regular, and takes the form of an arc of a pale yellow colour, the edges of which are diffuse, and the extremities resting on the horizon; the bow swells upwards more or less slowly, its summit being constantly on the magnetic meridian or very nearly so. The luminous matter of the arc soon becomes divided regularly by

blackish streaks and is resolved into a system of rays: these rays are alternately extended and contracted, sometimes slowly, sometimes instantaneously; sometimes they would dart out increasing and diminishing suddenly in splendour. The inferior parts of the feet of the rays present always the most vivid light, and form an arc of greater or less regularity. The length of these rays was often very varied, but they all converged to that point of the heavens indicated by the direction of the south pole of the dipping needle. Sometimes they were prolonged to the point where their directions intersected and formed the summit of an enormous dome of light. The bow would then continue to ascend towards the zenith; it would experience an undulatory motion in its light; that is, from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from *west* to east than in the opposite direction. Sometimes, though rarely, a retrograde motion would take place immediately afterwards; and as soon as this wave of light had run successively over all the rays of the aurora from west to east, it would return in the contrary direction to the point of its departure. The bow thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a riband, or of a flag agitated by the wind, as represented in Fig. 128.

Fig. 128.



Sometimes one, sometimes both of its extremities would desert the horizon, and then its folds would become more numerous and marked; the bow would change its character and assume the form of a long sheet of rays returning into itself and consisting of several parts forming graceful curves. The brightness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude. These rays would rapidly dart out and curves would be formed and developed like the folds of a serpent; then the rays

would assume various colours; the base would be blood-red, the middle pale emerald green, and the remainder would preserve its clear yellow hue. These colours always retained their respective positions, and they were of admirable transparency, the brightness would then diminish, the colours disappear, and all would be extinguished, sometimes suddenly, and sometimes gradually. After this disappearance fragments of the bow would be re-produced, would continue their upward movement and approach the zenith: the rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented thus the appearance of a larger zone of parallel rays, could be estimated; then the vertex of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed; at that moment the rays would be seen in the direction of their feet; if they were coloured they would appear as a large red band, through which the green tints of their superior darts could be distinguished; and if the wave of light above mentioned passed along them, their feet would form a long sinuous undulating zone while throughout all these changes, the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms. In the mean time new arcs are formed, either commencing in the same diffuse manner, or with perfectly formed and very vivid rays; they succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, forming as many bows, having their ends supported on the earth, and in their arrangement resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone, traversing the heavens and disappearing towards the south, becoming rapidly feeble after passing the zenith. If we can picture to our imagination all these vivid rays of light issuing forth with splendour, and varying continually and suddenly in their length and brightness, coloured at intervals with beautiful red and green tints, with waves of light undulating over them, the whole firmament presenting one immense and magnificent dome of light reposing on the snow-covered base, supplied by the ground, which itself serves as a dazzling frame for a sea calm and black as a pitchy lake, some idea may be obtained of the splendid spectacle which is presented to him who witnesses the aurora from the bay of Alten."

During the winter of 1838—9, between September, 1838, and April, 1839, M. Lottin observed 143 auroras; they were most

frequent during the period while the sun remained below the horizon, that is from the 17th of November to the 25th of January. During those nights he observed 70 auroras, without counting those which were rendered invisible by a clouded sky, but the presence of which was indicated by the disturbance they produced on the magnetic needle.

It is very rarely that an aurora is observed complete in any but the northern regions; sometimes the corona is vague and uncertain; sometimes the bow is either incomplete in itself or is divided into several points; at other times the light is intercepted by clouds which modify both the colour and the depth of the borders. Many other circumstances concur in interfering in various ways with the regular form of the aurora borealis.

(303) Whether the "magnetic storms" manifested by auroral display share with electric storms the phenomena of sound as well as of light appears doubtful. Nairne, Cavallo, and Hearne, at the mouth of the Coppermine River, and Henderson in Iceland, each heard "hissing sounds," which they regarded as connected with the aurora, but which Wentzel attributed to the contracting of the snow from the sudden increase of cold. Parry, Franklin, and Richardson, who have seen thousands of northern lights in different parts of the world, never heard any noise. The height of the aurora is likewise an uncertain point, the results of different measurements giving heights varying from a few thousand feet to several miles. The most modern observers seem, however, disposed to place the seat of the phenomenon, not at the limits of the atmosphere, but in the region of clouds; and they even believe that the rays of the aurora may be moved to and fro by winds and currents of air.

(304) Amongst the theories that have been proposed to explain auroras, that of Biot is perhaps characterised by the greatest ingenuity. He first determined that the phenomenon was placed within the limits of our atmosphere, and that it is connected either with the atmosphere, or with some matter suspended in it. Now, that its cause, whatever it may be, has an intimate relation with that of terrestrial magnetism is demonstrated by the fact, that the rays or columns of light are always parallel to the dipping-needle, and that the bows, coronæ, and other visible forms which the phenomena affect, are always symmetrically placed with respect to the magnetic meridian. Biot assumed also, that the aurora borealis is composed of real clouds of luminous matter, floating in the atmosphere, which frequently arrange themselves in series of lines or columns, parallel to the dipping-needle. What is the nature of this matter? This question is answered by Biot in the following manner (*Lardner and*

Walker's Electricity, vol. ii. p. 235): "Among material substances certain metals alone are susceptible of magnetism; since, then, the luminous matter composing the aurora obeys the magnetic influence of the earth, it is very probable that the luminous clouds of which it consists are composed of metallic particles, reduced to an extremely minute and subtile form. This being admitted, another consequence will immediately ensue, such metallic clouds, if the expression be allowed, will be conductors of Electricity, more or less perfect, according to the degree of proximity of their constituent particles. When such clouds arrange themselves in columnar forms, and connect strata of the atmosphere at different elevations, if such strata be unequally charged with Electricity, the electrical equilibrium will be re-established through the intervention of the metallic columns, and light and sound will be evolved in proportion to the imperfect conductibility of the metallic clouds arising from the extremely rarefied state of the metallic vapour or fine dust of which they are constituted. All the results of electrical experiments countenance these suppositions. When the phenomena are produced in the more elevated regions, where the air is highly rarefied, little resistance being opposed to the motion of the electric fluid, *light* alone is evolved without sensible sound, as is observed when Electricity is transmitted through exhausted tubes; but when the aurora is developed in the lower regions of the atmosphere, it would produce the hissing and cracking noise which appears to be heard on some occasions. If the metallic cloud possess the conducting power in a high degree, the electric current may pass through it without the evolution of either light or sound, and thus the magnetic needle may be affected as it would be by an aurora, at a time when no aurora is visible. If any cause alter the conductibility of these columnar clouds, suddenly or gradually, a sudden or gradual change in the splendour of the aurora would ensue.

According as those clouds advance over more southern countries, the direction of their columns being constantly parallel to the dipping-needle, they take gradually a more horizontal position, and, consequently, the strata of atmosphere, at their extremities, become gradually less distinct, and, therefore, more nearly in a state of electrical equilibrium; hence it follows, that as the latitude diminishes the appearance of aurora becomes more and more rare; until, in the lower latitudes, where the columns are nearly parallel to the horizon, such phenomena are never observed."

(305) The formation of these luminous metallic clouds is thus ingeniously accounted for by Biot: "The magnetic pole, or its vicinity, is evidently the point from which these columnar masses of

meteoric light proceed; therefore the extremely minute rays composing these columns must issue from the earth in that region. Now it is well known, that that part of the globe is, and always has been, characterised by the prevalence of frequent and violent volcanic eruptions; and several volcanoes have been, and still are, in activity round the place where the magnetic pole is situate. These eruptions are always accompanied by electric phenomena. Thunder issues from the volcanic clouds, ejected by the craters; and these clouds of volcanic dust, thus charged with Electricity, are projected to great heights, and carried to considerable distances through the air, carrying with them all the Electricity taken from the crater.

These vast eruptions, issuing from depths so unfathomable that they seem almost to penetrate the globe, and issuing with such violence from the gulfs by which they are projected into the atmosphere, must necessarily produce strong vertical currents of air, by which the volcanic dust will be carried to an elevation exceeding that of common clouds. To this it may be added, that more recent observations have rendered it highly probable, if not certain, that metallic matter, and more particularly iron, in a pure uncombined state, is frequently precipitated from clouds in thunder-storms."

(306) Such is the theory of the French philosopher. More recently De la Rive (*Phil. Mag.* vol. xxxiv. p. 286) has put forth another view, founded on the following considerations: Atmospheric Electricity has its origin in the unequal distribution of temperature in the strata of the atmosphere; *positive* Electricity proceeds from the hot part of a body to the cold; and negative Electricity moves in a contrary direction, hence the lower column of the atmosphere is constantly negative, and the upper column positive. The difference is more marked in our latitudes in summer than in winter, and more striking in general in the equatorial than in the polar regions. The negative state of the lower column is communicated to the earth, on which it rests, and thus positive Electricity increases with the height of the atmosphere.

The opposite electrical states of the upper and lower regions of the air undergo neutralization when the tension reaches a certain degree of energy, by humidity, rain, snow, &c. De la Rive conceives that, at the polar regions, the positive Electricity of the atmosphere combines readily with the negative there accumulated on the earth, because of the great humidity of the air in those regions, *a current is thus formed*, for the Electricity returns by the surface of the earth from the poles to the lower portion of the stratum, from whence it started. The current is from south to north in the upper regions of the atmosphere, and from north to south on the surface of the earth.

The same takes place in both hemispheres, consequently, for an observer, travelling from north to south, the current would proceed in the same direction, from the north pole to the equator, and in a contrary direction, from the equator to the *south* pole.

The aurora borealis is the luminous effect of these currents, travelling in these high regions towards the north pole, and is thus explained: when the sun, having passed into the southern hemisphere, no longer heats so much *our* hemisphere, a condensation of moisture, in the form of ice or snow, takes place round the polar regions, and Electricity is hereby conducted to the surface of the earth in the form of electric discharges. When the clouds are partial, *halos* are formed. The identity between the light of the aurora and electric light is proved by well-known experiments. The light produced by the electric discharge in highly rarefied, but perfectly *dry* air is very faint; the luminous effect is, however, greatly increased when moisture is present.

(307) The reason why these phenomena appear at the *magnetic* and not at the *terrestrial* pole, is illustrated experimentally by De la Rive in the following manner: "Place the pole of a powerful electro-magnet underneath the surface of mercury, connected with the negative pole of a powerful galvanic battery; bring over and near it the positive pole, armed with a charcoal point, a voltaic arc is formed, and the mercury is agitated above the magnet; luminous currents rotate round the pole, throwing out occasionally brilliant rays. There is always, as in the case of the aurora borealis, a dark portion in the form of a circular point, over the pole of the magnet. With a continuous current of ordinary Electricity, arriving at the pole of a powerful electro-magnet in moist rarefied air, luminous effects still more similar to those of the aurora borealis are obtained. These phenomena result from the action of magnets on currents, and the same should apply to the action of the magnetic pole of the earth. A noise is sometimes heard attending the aurora, exactly similar to that which the voltaic arc produces in the action of magnetism. A sulphureous smell (ozone?) likewise accompanies the aurora; the aurora likewise disturbs the magnetic needle in an irregular manner; Matteucci observed this in the Electric Telegraph between Ravenna and Pisa; as did also Mr. Barlow (*Phil. Mag.*, vol. xxxiv., p. 344) in the telegraph apparatus on the Midland line.

(308) At the meeting of the British Association at Cork, in August, 1843, Mr. Nott (*Athenæum*) described the following experiment, illustrative of the phenomena of the aurora borealis: "A globe of steel was magnetized by causing magnetizing bars to traverse it from the equator to the poles, whilst it was in rapid rotation; it was

then placed in similar electric circumstances to those which the earth was conceived to be in, and regarding that region of the atmosphere immediately over the torrid zone as the principal seat of atmospheric Electricity, it was thought that if the globe were surrounded with a ring that would bear approximately the same proportion to the globe, as this region of the atmosphere does to the earth, and both oppositely electrized, the action of the Electricity of the ring upon the air immediately enveloping the globe would place the latter in nearly similar electric circumstances to those of the earth. If then the aurora were an electric phenomenon, that is, a discharge of free Electricity, taking place from the pole of the earth, rendering the vortex, supposed to be immediately over the pole luminous, from the great rarefaction of the air within it, and passing over our atmosphere to the upper stratum of the equatorial region, an analogous effect ought to be produced by increasing the electric intensity of the artificial globe. Accordingly it was found, that on insulating the ring, and connecting it with the prime conductor of the resinous plate of the *rheo-electric* machine (a machine consisting of two parallel plates, one of glass and the other of resin, rotating on the same axis, and provided with separate rubbers), and on connecting the insulated globe by one of its poles with the vitreous conductor, and placing it so that its equator was surrounded by the ring, a truly beautiful and luminous discharge took place between the unconnected pole and the ring. A dense atmosphere was most favourable for this experiment, the light had then the appearance of a brilliant ring, the under part, towards the globe, being comparatively dark, while above, all round the axis, were foliating diverging flames, one behind the other. When the atmosphere was very dry, it had merely the appearance of a beautiful electric brush.

(309) Faraday has thrown out the idea (though with his usual caution), that the aurora borealis and australis may be connected with currents of Electricity induced by the earth's rotation. "I hardly dare venture," he says (*Ex. Resear.*, par. 192), "even in the most hypothetical form, to ask whether the aurora borealis and australis may not be the discharge of Electricity thus urged towards the poles of the earth, from whence it is endeavouring to return by natural and appointed means above the earth, to the equatorial regions. The non-occurrence of it, in very high latitudes, is not at all against this supposition; and it is remarkable that Mr. Fox, who observed the deflections of the magnetic needle at Falmouth by the aurora borealis, gives that direction of it which perfectly agrees with the present view. He states, that all the variations at night were towards the east, and this is what would happen if electric currents

were setting from south to north in the earth under the needle, or from north to south in spheres above it." Mr. Nott's ingenious experiment, above described, may be considered as, in some degree, an experimental illustration of this theory.

(310) Recent experiments (*Humboldt*) have failed to show a connection between polar light and atmospheric Electricity, since during the finest auroras no change has been detected in very sensitive electrometers. On the other hand, all the three manifestations of terrestrial magnetism, the declination, inclination, and force, are affected in a very sensible manner, the same end of the needle being sometimes attracted and sometimes repelled in the course of the same night. The luminous phenomenon is regarded by Humboldt as the restoration of the equilibrium temporarily disturbed, the termination of a magnetic storm, and the effect on the needle varies with the intensity of the discharge. The aurora is not to be regarded as the cause of the magnetic perturbation, but as the result of a state of "telluric activity," excited to the production of a luminous phenomenon; an activity which manifests itself on the one hand by the fluctuations of the needle, and on the other by the appearance of the brilliant auroral light. A great difference between an electrical and a magnetic storm is, that the former is usually confined to a small space, beyond which the state of Electricity in the atmosphere remains unchanged; the latter, on the other hand, manifests its influence on the march of the needle over large portions of continents, and far from the place where the evolution of light is visible. "That the aurora," says Humboldt, "is a magnetic phenomenon, has, by Faraday's brilliant discovery of the evolution of light by the action of magnetic forces, been raised from a mere conjecture to an experimental certainty. The fact which gives to the phenomenon its greatest importance is that the earth becomes *self-luminous;* that besides the light which as a planet it receives from the central body, it shows a capability of sustaining a luminous process proper to itself, and this going on almost uninterruptedly in the polar regions leads us by analogy to the remarkable phenomenon presented by Venus when the portion of that planet not illumined by the sun is seen to shine with a phosphorescent light of its own." It is not, he adds, improbable the moons of Jupiter and the comets radiate a light *generated by themselves* in addition to the reflected light which they receive from the sun.

(311) *Induction of atmospheric Electricity on the wires of the Electric telegraph.*—According to the observations of Professor Henry of Philadelphia (*Phil. Mag.* vol. xxx. p. 186), the wires are sometimes struck by a direct discharge of lightning which is seen coursing along

the wire in a stream of light; sometimes passing with explosions resembling the reports of rifles down the poles in succession. These *lateral* explosions are referred to the charge of the surface of the wire by a wave of the fluid, during the transmission of the Electricity which tends to give off sparks to neighbouring bodies, like the conductor of a machine. The discharge from the clouds does not generally consist of a simple wave of Electricity, but of a number of discharges in rapid succession along the same path, whence the wire of the telegraph is capable of transmitting an immense quantity of the fluid thus distributed over a great length of the conductor. Henry thinks that when the discharge takes place, a disturbance of the electrical *plenum* existing throughout all terrestrial space occurs, the state of rest being attained by a series of diminishing oscillations or waves, which, by their reflections, enhance the tendency of the fluid to fly from the conductor.

(312) The natural state of the telegraph-wire may be disturbed without the presence of a thunder cloud, by the passage of currents of Electricity from one portion of space to another, the electrical condition of the atmosphere surrounding the wire at one place being different from that at another. A difference of elevation will do this, as kite experiments abundantly testify, so that if the line of the telegraph passes over an elevated mountain ridge, there will be continually, even during clear weather, a current from the more elevated to the lower points of the conductor: vapour, fogs, snow, and rain at one end of the wire, and not at the other, may likewise determine currents of Electricity of sufficient power to set the marking machine of the telegraph in action. The natural Electricity of the telegraph-wire may even be disturbed by the induction of a distant cloud moving first towards and then from the wire, though such currents would be feeble.

(313) A fruitful source of disturbance of the needles is the powerful currents produced by induction, by flashes of lightning occurring perhaps many miles off. This is illustrated by the following experiment of Henry's: By sending sparks from a machine through a parallelogram of about sixty feet by thirty of copper wire suspended by silk strings round the ceiling of a room, a current was induced in a second similar parallelogram placed immediately below the first in the cellar of the building, through two floors and thirty feet distant, sufficiently powerful to magnetize needles; that similar effects may be produced by atmospheric Electricity was proved, by soldering a wire to the metallic roof of the house, and passing the other end down into a well; at every flash of lightning a series of currents, in alternate directions, was produced on the wire. Sparks have indeed

been seen on the railroad itself, at the breaks of the continuity of the rail, with every flash of a distant thunder cloud. Every discharge in the heavens must, therefore, produce inductive effects to a greater or less degree in the telegraph wires. In the Telegraph Office at Philadelphia, Henry observed sparks passing from the wire to a metallic surface, in connection with the earth through nearly an inch, during the raging of a storm at Washington; such, indeed, was the quantity and intensity of the current, that the needle of an ordinary vertical galvanometer with a short wire, and not by any means sensible, was moved by it several degrees, its pungency was also very great. By erecting at intervals along the line metallic rods about half an inch from the wire of the telegraph, particularly at places where the line crosses the river, and near the stations, all personal danger may be avoided. It is well known that small birds have sometimes been found hanging by their claws dead from the wire, having probably been killed by one of these inductive discharges. There seems no way of obviating the effect of these inductive currents on the telegraph; but during thunder weather it would be advisable to *increase* the strength of the batteries, and to *diminish* the sensibility of the magnetic needles.

(314) According to the observations of M. Baumgartner (*Revue Scientifique, Dec.*, 1849), the direction of the atmospheric eclectric currents along the telegraph wires is from Vienna to Sommering during the day, and inverse during the night, the change of direction taking place after the rising and setting of the sun. The regular current is less disturbed by irregular currents when the air is dry and the sky serene, than when the weather is rainy, and the current is more intense with short than with long conductors. When the sky is cloudy, and the weather stormy, currents are observed sufficiently intense to affect the telegraphic indicators, and the action is stronger on the approach of a storm. Mr. Barlow has also made some curious observations on the direction of the disturbance of the telegraph needle. He found (*Phil. Mag.* vol. xxxiv. p. 344), that in two telegraphs proceeding northerly and north easterly, *i. e.* from Derby N. towards Leeds, and from Derby N.E. towards Lincoln, the direction of the disturbance was always contrary to those proceeding southerly and south-westerly, *e. g.* from Derby S. towards Rugby, and from Rugby S.W. to Birmingham. He found currents at all times perceptible in telegraph wires between two earth conductors, but not so if the wires have no earth connection; that the changes of force and direction were simultaneous at both ends of a wire forty-one miles long, the current passing direct from one earth connection to the other; that there is a daily movement of the galvanometer needle,

similar to that of the horizontal magnetic needle, produced by the electric currents travelling in one direction from eight A.M., to eight P.M., and returning in the opposite direction during the remainder of the twenty-four hours; the movement of the galvanometer needle being subject to disturbances which are the greatest during the prevalence of *auroræ;* that the direction in which these currents alternate is from N.E. to S.W., the effect not depending on the direction of the wire itself, but on the relative direction of the two earth connections.

Barlow also made simultaneous observations with the galvanometer and a declinometer needle, from which it appeared that taking the mean of many observations that part of the day in which the currents flow S. (*i. e.* from eight or nine A.M. till evening), the variation of the declinometer needle is W., and that, during the night and early in the morning, at which time the currents travel N., the variation is E., also that those large disturbances called magnetic storms are simultaneous on both instruments.

Barlow attributes these currents to thermo-electric action in the crust of the earth, while De la Rive considers them to originate in the atmosphere.

(315) The extraordinary influence of the *aurora borealis* on the needles, and sometimes even on the bells of the electric telegraph, is thus noticed by Mr. Walker, superintendent of the Electric Telegraphs to the South Eastern Railway Company, in his entertaining little work, entitled, "Electric Telegraph Manipulation:" "At such times needles move just as if a good working current were pursuing its ordinary course along the wires, they are deflected this way or that, at times with a quick motion, and changing rapidly from side to side, many times in a few seconds, and, at other times, moving more slowly, and remaining deflected for many minutes with greater or less intensity, their motions being inconstant and uncertain. These phenomena have occurred less frequently on the part of the line between Reigate and Dover, which runs nearly E. and W.; on the part between London and Reigate, which is nearly N. and S. When, however, they do make their appearance on the telegraph in those parts, we are prepared to expect auroral manifestations when the night arrives, and we are rarely disappointed. The deflections in their variations appear to coincide with the various phases of the aurora. On the branch line running from Ashford to Ramsgate, these deflections have been a much more common occurrence, even when the other parts of the line were unaffected, and when no auroral phenomena were noticed. This branch nearly coincides with the curve of *equal dip*. A dipping needle inclines downward to the

same angle 68°40′ at all places along this curve; whether there is any relation between these two facts remains to be investigated. . . . The needles are also subject to feeble secular deflections, corresponding with certain hours of the day. The wires also at times collect Electricity from the atmosphere, and affect the needles."

(316) Some remarkable phenomena, observed at the works of the Electric Telegraph Company, by Mr. Latimer Clarke, have recently attracted the attention of Professor Faraday, and are regarded by him as affording striking illustrations of the truthfulness of his views respecting the mutually dependent nature of induction, insulation, and conduction (83).

The telegraph wire is covered with gutta percha, the insulation of which is tested by submerging the coils sometimes 100 miles at a time in water, and connecting one end through a galvanometer with one end of an insulated intensity voltaic battery, the other end of which is in communication with the earth; any deficiency of insulation in the wire is immediately shown by the deflection of the galvanometer, yet so perfect is the insulating power of the gutta percha that the needle seldom passes through more than 5°. On making contact between the free end of the battery (of 360 pairs of plates 4×3 inches), and one end of the immersed wire, and then breaking it, a smart shock could be received by a person touching the wire, and also, at the same time, a wire in communication with the earth; and this even after the contact had been broken two or three minutes; a fuze could also be fired, and the galvanometer powerfully affected; none of these effects were produced when the wire was suspended in air.

(317) On consideration it became evident that the results obtained with the submerged wire were due to a charging of the wire by the battery, that it constituted in fact an immense Leyden arrangement; the copper wire, exposing a surface of nearly 8,300 square feet, becomes charged *statically* with the Electricity from the battery, and acting by induction through the gutta percha, producing the opposite state on the surface of the water touching the gutta percha, and forming the outer coating; the intensity of the static charge acquired is only equal to the intensity at the pole of the battery, but the quantity, because of the immense extent of the coated surface, is enormous: hence the striking character of the results. The reason why no such effects are obtained with a wire suspended in air is simply because there is in this case no outer coating correspondent to the water, and as, therefore, there was no induction, so the inner wire could not become charged. Precisely similar phenomena were exhibited by the subterraneous wires, covered with gutta percha and

enclosed in metallic tubes, existing between London and Manchester. These wires, when all connected together, offered a series of above 1,500 miles, which as the duplications return to London could be observed by one experimenter at intervals of about 400 miles, by the introduction of galvanometers at these returns. When the whole 1,500 miles were included, it required two seconds for the electric stream from a pole of the battery to reach the last instrument; and when the battery was cut off, the last galvanometer showed that a current was flowing on to the end of the wire, whilst there was none flowing in at the beginning. Again, if a short touch was made of the battery pole against the first galvanometer, it could be deflected, and could fall back into its neutral condition before the electric power had reached the second galvanometer, which in its turn would be for an instant affected, and then left neutral before the power had reached the third, &c.; a wave of force having been sent into the wire which gradually travelled along it, and made itself evident, at successive intervals of time, in different parts of the wire. It was even possible, by adjusted touches of the battery, to have two simultaneous waves in the wire, following each other, so that at the same moment that the last galvanometer was affected by the first wave, the first or second instrument was affected by the second wave. It was possible also to cause two currents to flow in opposite directions from each extremity of the wire, while no current was going into it from any source, or by a quick contact between the battery and the first galvanometer, to cause a current to enter into, and return out of, the wire at the same place, without any sensible part of it travelling onwards to the other extremity.

(318) The effects above described depend upon *lateral induction*, and are necessary consequences of the principles of conduction, insulation, and induction, three terms which, according to Faraday's view, are in their meaning inseparable from each other (39—82). In the subterraneous or submerged wire, the induction consequent upon charge, instead of being exerted almost entirely at the moment within the wire, is to a very large extent determined *externally;* and so the discharge or conduction being caused by a lower tension, therefore requires a longer time.

(319) It is this lateral induction of the wire carrying a current which has occasioned such discrepancies in the measurements of the velocity of Electricity as given by different experimenters.

	Miles per second.
Thus Wheatstone (154), with copper wire, made it. . .	288,000
* Walker, in America, with telegraph iron wire . .	18,780

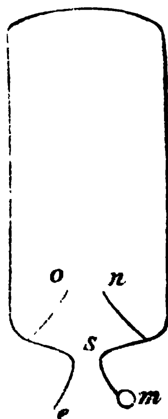
* Liebig and Kopp's Report, 1850 (Translated), p. 168.

	Miles per second.
* O'Mitchell, in America, with telegraph iron wire	28,524
* Frizeau and Gonnelle, copper wire	112,680
* Ditto . . . . iron wire	62,600
† A.B.G., copper, London and Brussels telegraph .	2,700
† Ditto, copper, London and Edinburgh telegraph	7,600

But in regard to the long circuits operated within the above experiments, the conducting power of the wires cannot be understood whilst no reference is made to their lateral static induction, or to the conditions of intensity and quantity which then come into play; especially in the case of short or intermitting currents; for then static and dynamic are constantly passing into each other.

(320) The following striking proof of the variations of the conduction of a wire by the variation of its lateral static inductions was shown by Faraday in the lecture at his Royal Institution (Jan. 20, 1854), in which these associated cases of current and static effects were first described. A long copper wire, having at the end *m* a metal ball, was insulated in the air; its end *e* connected with the earth, and the part near *m* and *e* brought within half an inch of each other at *s*; then an ordinary Leyden jar being charged sufficiently, its outside connected with *e*, and its inside with *m*, gave a charge to the wire which, instead of traversing wholly through it, though it be so excellent a conductor, passed in large proportion through the air at *s* as a bright spark; for with such a length of wire the resistance in it is accumulated until it becomes as much or perhaps even more than that of the air for Electricity of such high intensity. This is an old experiment. It was varied by Faraday by adjusting the interval at *s*, so that the spark just freely passed there, and then connecting *n* and *o* with the inside and outside of an insulated Leyden jar, the spark now never appeared at *s*, though when the jar was away it could be made to appear twenty times without a single failure. The reason was, that in consequence of the *lateral induction* momentarily allowed by the interposition of the jar between the side wires, the intensity was lowered, and the quantity of Electricity though always the same, was not enough to strike across the interval at *s*, but was finally occupied altogether in the wire, which in a little longer time than before effected the whole discharge.

Fig. 129.



* Liebig and Kopp's Report, 1850 (Translated), p. 168.

† Athenæum, January 14, 1854, p. 54.

(321) Beautiful illustrations and records of the facts above stated were obtained by Mr. Clarke with a Bain's *printing* telegraph. The pens, three in number, were iron wires, under which there was made to pass by machinery a band of paper moistened with solution of ferro-cyanide of potassium, and thus regular lines of Prussian blue were produced whenever the current was transmitted, and the line of the current was recorded. The following experiments were made: the three lines were side by side, and about 0·1 of an inch apart. The pen *m* belonged to a circuit of only a few feet of wire, and a separate battery: it told whenever the contact key was put down by the finger; the pen *n* was at the earth end of a long *air* wire, and the pen *o* at the earth end of a long *subterraneous* wire, and by arrangement the key could be made to throw the Electricity of the chief battery into either of these wires, simultaneously with the passage of the short circuit current through the pen *m*. When the pens *m* and *n* were in action, the *m* record was a regular line of equal thickness, showing by its length the actual time during which the Electricity flowed into the wires, and the *n* record was an equally regular line parallel to and of equal length with the former, but the least degree behind it, thus indicating that the long air wire conveyed its electric current almost instantaneously to the further end. But when pens *m* and *o* were in action, the *o* line did not begin until some time after the *m* line, and it continued after the *m* line had ceased, *i.e.*, after the *o* battery was cut off. Furthermore, it was faint at first, grew up to a maximum of intensity, continued at that as long as battery contact was continued, and then gradually diminished to nothing. Thus the record *o* showed that the wave of power took time in the water wire to reach the further extremity: by its first faintness it showed that power was consumed in the exertion of lateral static induction along the wire; by the attainment of a maximum and the after equality, it showed when this induction had become proportionate to the intensity of the battery current; by its beginning to diminish it showed when the battery current was off; and its prolongation and gradual diminution showed the time of the outflow of the static Electricity laid up in the wire, and the consequent regular falling of the induction which had been as regularly raised.

With the pens *m* and *o* the conversion of an intermitting into a continuous current could be beautifully shown, the earth wire, by the static induction which it permitted, acting in a manner analogous to the fly-wheel of a steam engine, or the air-spring of a pump. Thus when the contact key was regularly but rapidly depressed and raised, the pen *m* made a series of short lines, separated by intervals

of equal length. After four or more of these had passed, then pen *o*, belonging to the subterraneous wire, began to make its mark, weak at first, then rising to a maximum, but always continuous. If the action of the contact key was less rapid, then alternate thickening and attenuation appeared in the *o* record; and if the introductions of the electric current at the one end of the earth wire were at still longer intervals, the records of action at the other end became entirely separated from each other; all showing beautifully how the individual current or wave, once introduced into the wire, and never ceasing to go onward on its course, could be affected in its intensity, its time, and other circumstances, by its partial occupation by static induction. By other arrangements of the pens *n* and *o*, the near end of the subterraneous wire could be connected with the earth immediately after the separation from the battery, and then the back flow of the Electricity, and the time and manner thereof, were beautifully recorded. Many other variations of these experiments were made.

(322) Mr. Faraday concluded the lecture, of which the above is an abstract, by some observations on the terms *intensity* and *quantity*, terms which, or equivalents for them, cannot, he thinks, be dispensed with by those who study both the *static* and the *dynamic* relations of Electricity. Every current where there is resistance has the *static* element and induction involved in it; whilst every case of insulation has more or less of the *dynamic* element and conduction. The idea of intensity, or the power of overcoming resistance, is as necessary to that of Electricity, either static or current, as the idea of pressure is to steam in a boiler, or to air passing through apertures or tubes, and we must have language competent to express these conditions and these ideas. He has never found either of these terms lead to any mistakes regarding electrical action, or give rise to any false view of the character of Electricity or its unity; he cannot find other terms of equally useful significance with these, or any which, conveying the same idea, are not liable to such misuse as these may be subject to; and, moreover, the present investigation has shown him their great value and peculiar advantage in electrical language.

CHAPTER VII.

GALVANIC OR VOLTAIC ELECTRICITY.

Various forms of the galvanic or voltaic battery—Law of Ohm—Wheatstone's application—The Rheostat.

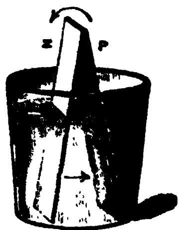
(323) *Galvanic arrangements—Volta's fundamental experiment.*— Two polished metallic discs, one of copper and the other of zinc, about three inches in diameter, and each provided with an insulating handle, are brought into contact, holding them by their handles; they are then separated, especially avoiding friction, and brought successively into contact with the collecting plate of a condensing electroscope (92), the zinc plate is found to be slightly charged with *positive*, and the copper plate with *negative* Electricity. The charge from one contact is very feeble, but by repeating the operation eight or ten times, taking care to discharge the discs each time by touching them with the finger, a considerable amount of divergence of the leaves of the electroscope may be produced. The electric effects thus obtained were considered by Volta to be due to a peculiar electro-motive force, under which metals, by simple contact, tend to assume opposite electrical states, and this view has been supported, in recent times, by a brilliant array of profound electricians, including Pfaff, Marianini, Fechner, Zamboni, Matteucci, &c.; on the other hand, a powerful mass of evidence against it, and in favour of the theory that the source of power is *chemical action alone*, has been brought by numerous equally distinguished *savans*, including Fabroni, Wollaston, Œrsted, Becquerel, De la Rive, Schoenbein, Faraday, Grove, &c. We shall endeavour, in a future chapter, to present an unbiassed view of both sides of this interesting philosophical question.

(324) It has been shown by Mr. Grove (*Elect. Mag.* vol. i., 57), that Volta's experiment is equally successful if the contact is *prevented* by the interposition of a circle of card, and he conceives the action between the discs to be somewhat similar to that which occasions a coin, when allowed to remain for some time on a polished plate, to leave behind it on the metal a faint picture, viz., to a radiation between the metals, on account of difference in temperature,

whereby a chemical disturbance takes place. It is true, that to this experiment some objections have been raised. It has been urged, that the mere interposition of a *rim of paper* may not have prevented actual metallic contact in those portions of the discs that were not protected; others have assumed, that the exciting cause is the friction produced by the pressure of the discs against the paper. Mr. Gassiot has, however (*Phil. Mag.*, Oct. 1844), repeated the experiment in the following unexceptionable manner: two plates, one of copper and the other of zinc, four inches in diameter, were attached to the insulated pillars of his micrometer electrometer (*Phil. Trans.* 1840, p. 185); the plates were carefully approximated to about $\frac{1}{100}$th of an inch. When thus adjusted, a copper wire was attached to each of the plates and also to the discs of the electroscope, which were fixed at about $\frac{1}{8}$th of an inch apart; the leaf of the electroscope was raised, so as to allow it to swing clear of the two discs, and when not excited, to remain equidistant from each: thus arranged, the apparatus is ready for the experiment. With one hand the experimenter holds a Zamboni's pile (337), so as to have one of its terminals within about an inch of the glass plate or cap of the electroscope, and with his other hand he separates the plates: immediately on separation the terminal of the pile is brought into contact with the cap of the electroscope, and the leaf will be attracted as follows:—if touched by the *minus* terminal of the pile, the leaf of the electroscope will be attracted to the disc in connection with the zinc plate, and if by the *plus* terminal, the leaf will be attracted to that in connexion with the copper plate, which are precisely the same results as follow the separation after *actual* contact. These results clearly show, that decided signs of electrical tension may be obtained *without any metallic contact.*

(325) Assuming that the Electricity excited by the contact of the copper and zinc plates is traceable to slight chemical action, it is easy to understand that increase of chemical action must give rise to increased augmentation of the electrical force. If we take two plates of different kinds of metal, platinum and zinc, for example, Figs. 130 and 131, and immerse them in pure water, touching each other, a galvanic circle will be formed, the water will be slowly decomposed, its oxygen becoming fixed on the zinc (the oxidable metal), and at the same time a current of Electricity will be transmitted through the liquid to the platinum, on the surface of which the other element of the water, namely, hydrogen, will make its appearance in the form of minute

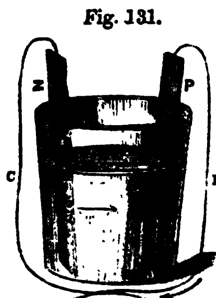
Fig. 130.



gas bubbles: the electrical current passes back again into the zinc at the points of its contact with the platinum, and thus a continual current is kept up: and hence it is called a galvanic *circle.* The moment the circuit is broken by separating the metals, the current ceases, but is again renewed on making them again touch either in or out of the water, as shown in the figures.

(326) If we now add a little sulphuric acid to the water, this effect will be much increased, because, in the first place, we make the liquid a better conductor; and, secondly, because the oxide of zinc is removed from the surface of the metal as fast as it is formed, being dissolved by the acid; and thus a new and clean surface is continually exposed. It is particularly to be observed, that the great increase in the quantity of Electricity generated is to be attributed almost entirely to the increased facility afforded for the decomposition of water, and has but little, if anything, to do with the formation of sulphate of zinc; not chemical action alone, but chemical decomposition being absolutely essential to the development of current Electricity. The force originates with the zinc, passes in the direction of the arrow through the liquid to the platinum, and thence back through the wires B C, to the zinc. This is called a *simple* galvanic circle.

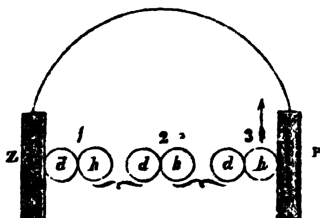
Fig. 131.



(327) To prove that the wire connecting the platinum and zinc plates is conducting a current of Electricity, we have only to place a nicely balanced magnetic needle above or below it, and we shall find that the needle will deviate from the magnetic meridian in obedience to laws that will be described hereafter; but, how are we to account for the singular appearance of hydrogen gas on the platinum? If we amalgamate the zinc plate, by immersing it in dilute sulphuric acid, and then rubbing it over with mercury, we shall find that a mixture of one part of sulphuric acid and ten of water will have no action on it *while alone;* the bright metallic surface will be soon seen covered with bubbles of hydrogen gas, which will adhere to it with considerable force, and thus protect it from further action: but on establishing a metallic communication between the zinc and the platinum, no matter in what manner, or by what circuitous a route, torrents of bubbles will rise from the latter metal, as if it were undergoing violent chemical action, while the zinc (the metal alone undergoing change) is oxidized and dissolved tranquilly and without any visible commotion. It is evident that we cannot explain this singular phenonenon on chemical grounds alone; but we must con-

sider the transference of the hydrogen to take place by the propagation of a decomposition through a chain of particles extending from the zinc to the platinum, as in Fig. 132, in which, for the sake of simplicity, the exciting liquid is supposed to be hydrochloric acid: when the metallic communication is established between the plates, that particle of hydrochloric acid in contact with the zinc undergoes decomposition, its chlorine combining with the metal, and its hydrogen displacing and combining with the chlorine of the second particle, the hydrogen of which combines with the chlorine of the third, and so on, till the platinum plate is reached, against which the hydrogen of the last particle of decomposed hydrochloric acid is evolved in a gaseous form, because it can find no particle of chlorine to combine with, and because it cannot enter into chemical union with the platinum. These changes and interchanges are precisely similar when dilute sulphuric acid is employed, substituting oxygen and hydrogen (from decomposed water) for chlorine and hydrogen; for, as we have already stated, the formation of sulphate of zinc has little, if anything to do with the business, it being to the decomposition of water that the effects are to be ascribed.

Fig. 132.



(328) Now there is nothing in the appearance of the liquid between the plates which would indicate the transfer of the disunited elements above alluded to; and the vessel which contains the acid may be divided by a diaphragm of bladder or porous earthenware, and the plates placed on each side of it, without interfering much with the general result. The force must be conceived to travel by a species of *convection*, and Mr. Daniell has offered the following illustration, to assist us in forming a first notion (*Introduction to Chemical Philosophy*, p. 413).

"When a number of ivory balls are freely suspended in a row, so as just to touch one another, if an impulse be given to one of the extreme ones, by striking it with a hard substance, the force will be communicated from ball to ball without disturbing them, till it reaches the more distant, which will fly off under its full influence. Such analogies are but remote, and must not be strained too far; but thus we may conceive that the force of affinity receives an impulse in a certain direction, which enables the hydrogen of the first particle of water, which undergoes decomposition, to combine momentarily with the oxygen of the next particle in succession: the hydrogen of this again with the oxygen of the next; and so on, till

the last particle of hydrogen communicates the impulse to the platinum, and escapes in its own elastic form."

(329) But it is not in the exciting liquid alone, that this remarkable transfer of elements takes place; the same power is propagated through the wire which connects the platinum and zinc plates together. To prove this, let the wire be divided in the middle, and having attached to each end a long slip of platinum foil, let each be immersed in a glass jar containing hydriodic acid; in a few seconds *iodine* will appear on that slip of foil which is in connection with the platinum plate and hydrogen gas on the other; so that, supposing a decomposing force to have originated in the zinc plate, and circulated through the exciting acid in the jar to the platinum, and onwards through the wires and the hydriodic acid back to the zinc: then the hydrogen of the hydriodic acid followed the same course, and discharged itself against the slip of platinum foil in communication with the zinc.

(330) It does not require two metals to form a galvanic circle, or even two different liquids, if other conditions are attended to. A current is established when a zinc plate is cemented into a box, and acted upon on one side by diluted acid, and on the other by solution of common salt; or, by acting on both sides by the same acid, one surface being rough and the other smooth, a communication being of course established between the two cells. Common zinc affords a good illustration of a simple galvanic circle: this metal usually contains about one per cent. of iron mechanically diffused over its surface. On immersion into diluted sulphuric acid, these small particles of iron and zinc form numerous voltaic circles, transmitting the current through the acid that moistens them, and liberating a large quantity of hydrogen gas.

(331) An important fact, of which a beautiful practical application was proposed by Davy, was early observed:—In proportion as the contact of two metals in an acid or saline solution increases the affinity of one of them for one element of the solution, it diminishes the liability of the other metal to undergo change. Thus when zinc and copper are united in diluted acid, the zinc is acted upon *more* and the copper *less* than if they were immersed separately. A sheet of copper undergoes rapid corrosion in sea-water, the green oxychloride being formed; but if it be associated with another metal more *electro-positive* than itself, such as zinc, it is preserved, and the zinc undergoes a chemical change. Davy found that the quantity of zinc requisite to effect a complete preservation of the copper was proportionably very small. A small round nail will preserve forty or fifty square inches, wherever it may be placed; and he found, that

with several pieces of copper connected by filaments, the fortieth of an inch in diameter, the effect was the same. Sheets of copper, protected by $\frac{1}{40}$ and $\frac{1}{100}$ part of their surface of zinc, malleable, and cast-iron were exposed during many weeks to the flow of the tide in Portsmouth harbour, their weight, both before and after the experiment, being carefully noted. When the metallic protector was from $\frac{1}{40}$ to $\frac{1}{150}$, there was no corrosion or decay of the copper; with $\frac{1}{200}$ to $\frac{1}{450}$ there was a loss of weight: but even $\frac{1}{1000}$ part of cast-iron saved a portion of the copper. Davy hoped to apply this principle to the preservation of the copper sheathing of ships; but unluckily it was found, that unless a certain degree of corrosion take place in the copper, its surface becomes foul from the adhesion of sea-weeds and shell-fish. The oxy-chloride, formed when the sheathing is unprotected, acts probably as a poison to these plants and animals, and thus preserves the copper free from foreign bodies, by which the sailing of the vessel is materially retarded. M. Reinsch proposes (*Jahrb. für Prakt. Pharm.* vii. p. 94) to cover the copper sheathing of vessels with a thin layer of arsenic in the moist way. This coating would cost very little, would not be acted upon by the salt water, and would prevent *mollusca* from adhering to the bottom of the vessel as effectually as verdigris.

(332) There are many modifications of the simple galvanic circle; the original cylindrical battery, Fig. 133, consists of a double cylinder of copper closed at the bottom to contain the acid, and a similar but smaller cylinder of zinc, which is kept from touching the sides of the copper, by pieces of cork; both are furnished with wires terminated by caps to contain mercury for the convenience of making and breaking the circuit. The quantity of Electricity set in motion by these simple circles, when on a large scale, is very great, though the intensity is very low. No physiological effects are experienced when the body is included in the circuit, nor is water decomposed; their heating powers are, however, so great, that they were called by Dr. Hare *calorimotors*. An arrangement on a very extensive scale was made at the Royal Institution, under the direction of Mr. Pepys, Fig. 134. A sheet of zinc, and one of copper, were coiled round each other, each being sixty feet long and two feet wide: they were kept asunder by the intervention of hair ropes, and suspended over a tub of acid, so that by a pulley, or some other simple contrivance, they could be immersed and removed. About fifty gallons of dilute

Fig. 133.

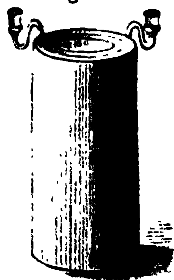
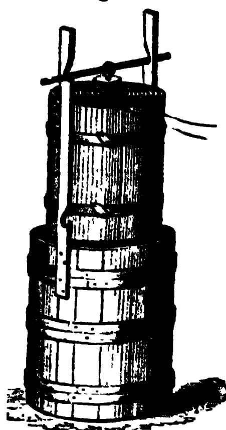


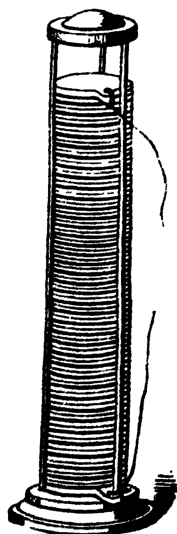
Fig. 134.



acid were required to charge this battery, and when it is stated that a piece of platinum wire may be heated to redness by a pair of plates, only four inches long and two broad, the calorific power of such an arrangement as the above may be imagined to have been immense. The energy of the simple circle depends on the size of the plates, the intensity of the chemical action on the oxidable metal, the rapidity of its oxidation, and the speedy removal of the oxide.

(333) In order to increase the *intensity* of the electrical current, with a view to the exhibition of its chemical and physiological effects, we increase the *number* of the plates; an arrangement of this sort is called the *compound* voltaic circle: it was the invention of Volta, and is hence called the voltaic pile. Now, the *quantity* of Electricity obtained from the voltaic pile is no greater than that from a single pair of plates, it is its *intensity* alone that is increased; an important fact which has received much elucidation from the important labours of Faraday.

Fig. 135.

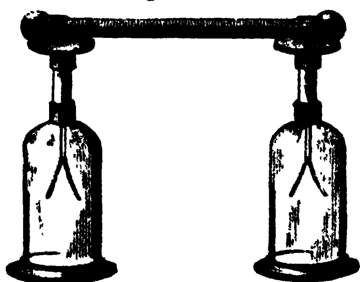


(334) The original instrument of Volta is shown in Fig. 135. It consists of a series of silver and zinc, or of copper and zinc plates, arranged one above another, with moistened flannel or pasteboard between each pair. A series of thirty or forty alternations of plates, four inches square, will cause the gold leaf electroscope to diverge: the zinc end with positive, and the silver end with negative Electricity, a shock will also be felt on touching the extreme plates with the finger, when moistened with water. This latter effect is much increased when the flannel or pasteboard is moistened with *salt* and water; in this case a small spark will be seen on bringing the extreme wires into contact, and water will be decomposed: from this we learn that the increase of chemical action by the addition of the salt, materially increases the *quantity* of Electricity set in motion; but the pile will not in any sensible manner increase the divergence of the gold leaves,—its *intensity*, therefore, is not materially augmented.

(335) An electric pile was constructed by De Luc, from which much useful information respecting the direction of the electric current in these cases of excitation may be derived. This instrument consists of a number of alternations of two metals, with paper interposed: the elements may be circular discs of thin paper, covered on one side with gold or silver leaf about an inch in diameter, and similar sized pieces of thin zinc foil, so arranged that the order of succession shall be preserved throughout, viz., zinc, silver, paper, zinc, silver, paper, &c. About five hundred pairs of such discs, enclosed in a perfectly dry glass tube, terminated at each end with a brass cap and screw to press the plates tight together, will produce an active column. The late intelligent electrician, Mr. Singer, constructed a *dry pile* on a much more extensive scale. It consisted of twenty thousand series of silver, zinc, and double discs of writing-paper: it was capable of diverging with ball electroscopes, and by connecting one extremity of the series with a fine iron wire, and bringing the end of this near the other extremity, a slight layer of varnish being interposed, *a succession of bright sparks could be produced*, especially when the point of the wire was drawn lightly over the surface. A very thin glass jar, containing fifty square inches of coated surface, charged by ten minutes' contact with the column, had power to fuse one inch of platina wire $\frac{1}{5000}$ of an inch in diameter. It gave a disagreeable shock, felt distinctly in the elbows and shoulders, and by some individuals across the breast. The charge from this jar would perforate thick drawing-paper, but not a card. It did not possess the slightest chemical action, for saline compounds tinged with the most delicate vegetable colours underwent no change, even when exposed for some days to its action.

(336) On examining the electrical state of the dry electric column, it is found to resemble that of a conductor under induction: in the centre it is *neutral*, but the ends are in opposite electrical states; and if one extremity be connected with the earth, the Electricity of the opposite end becomes proportionally increased: the zinc extremity is *positive*, and the silver or gold extremity *negative*: as may be proved by laying the column on the caps of two gold leaf electroscopes in the manner shown in Fig. 136, the leaves will diverge with opposite Electricities: if a communication be made between the instruments by a

Fig. 136.



metallic wire the divergence of the leaves will cease, but will again be renewed when such communication is broken. It is better to employ, in these experiments, an electroscope in which the gold leaves are suspended singly, as shown in Fig. 137, and so arranged as to admit of their being brought nearer to or carried further from each other. If in such an instrument the leaves are adjusted at a proper distance from each other, and the wire from which one is suspended connected with the zinc end, and the wire from which the other is suspended connected with the silver end of the column, a kind of perpetual motion will be kept up between the leaves; for, being oppositely excited, they will attract each other; and having by contact neutralized each other, they will separate for a moment, and again attract and separate as before. If both silver ends, or both zinc ends of two columns are connected with the two gold leaves a continued repulsion will be kept up between the leaves, they being then similarly electrified.

Fig. 137.



(337) A variety of amusing experiments has been devised, dependent upon this curious property of De Luc's column. Thus a small clapper may be kept constantly vibrating between two bells. This was the contrivance of Mr. Forster, who constructed a series of fifteen hundred groups, and by its continued action kept up the vibrations of the pendulum for a very long time. With twelve hundred groups, arranged by Mr. Singer, a perpetual ringing during fourteen months was kept up. We are informed by Mr. Singer, that De Luc had a pendulum which constantly vibrated between two bells for more than two years. A convenient modification of De Luc's column was contrived by Zamboni, by pasting on one side of a sheet of paper finely laminated zinc, and covering the other side with finely powdered black oxide of manganese. On cutting discs out of this prepared paper, and piling them upon each other to the number of 1000, taking care to press them together, a little pile is obtained, capable of diverging the gold leaves of the electrometer to the extent of half an inch. Mr. Gassiot describes (*Phil. Trans.* 1839) an arrangement which he has constructed, consisting of a series of 10,000 of Zamboni's piles. With this arrangement, he charged a Leyden battery to a considerable degree of intensity, and obtained direct sparks of $\frac{1}{50}$ of an inch in length. He ultimately succeeded in obtaining chemical decomposition of a solution of iodide of potassium, the iodine appearing at the end composed of the black oxide of manganese.

(338) Philosophers are divided in opinion respecting the source of the electric charge of the "dry pile," some supposing it due to the contact of the metals, while others trace it to the contact of the zinc with the small portion of moisture which is contained in the paper in its common hygrometric state. It is certain that a degree of moisture is indispensable to the action of the instrument; for the Electricity disappears altogether when the paper discs have lost their humidity by spontaneous evaporation, and the zinc becomes slowly corroded in the course of years; its charge appears to be altogether one of intensity, and after discharge requiring an interval of time for renewal. It is not improbable that the state of the atmosphere is in some way connected with the phenomenon, for the motion of the pendulum is subject to much occasional irregularity. De Luc and Mr. Hausman both observed that the action of the column was increased when the sun shone on it; but they conceived that the effect was not due to the heat of the sun's rays, because it was found that an instrument put together after the parts had been thoroughly dried by the fire had no power whatever, but that it became efficacious after it had been taken to pieces, and its materials had remained exposed all night to the air from which the paper imbibed moisture. Mr. Singer, however, remarks, that the power of the column is increased by a moderate heat, as his apparatus vibrated more strongly in summer than in winter, and the electrical indications were stronger when there was a fire in the room. Care should be taken not to allow the ends of the column to remain for any length of time in contact with a conducting body; for, after such continued communication, a loss of power will be perceived. When, therefore, the instrument is laid by, it should be insulated; and if it had previously nearly lost its action, it will usually recover it after a rest of a few days. The application of the dry pile to the electroscope has been already alluded to (52).

(339) When a series of some hundred couples of zinc and copper cylinders are arranged voltaically, and charged with common water, a battery is obtained, the Electricity of which is of a high degree of intensity, resembling that of the common electrical machine; indeed, by connecting the extremities of such an arrangement with the inner and outer coatings of a Leyden battery, it becomes charged so instantly that almost continuous discharges may be produced. An extensive series of the water-battery was constructed by Mr. Crosse, and the phenomena which it exhibited were of a very interesting character. It consisted of 2500 pairs of copper and zinc cylinders, most of which were enclosed in glass jars: they were all well insulated on glass stands, and were ranged on three long tables, well

protected from dust and from the light,—a situation which experience has shown Mr. Crosse to be most favourable for this peculiar form of the voltaic battery.

340) The following were some of the results obtained from this battery:—30 pairs afforded a slight spark, sufficient to pierce the cuticle of the lip, the hand making the communication being wetted; —130 pairs opened the gold leaves of the electrometer about half an inch;—250 pairs caused the gold leaves to strike their sides;—400 pairs gave a very perceptible stream of Electricity to the dry hand, making the connection between the poles, the light being very visible;—500 pairs occasioned that part of the dry skin which was brought in contact to be slightly cauterized, more especially at the *negative* side;—1200 pairs gave a *constant small stream* of the fluids, between two wires or two pieces of tin-foil, placed $\frac{1}{100}$ of an inch apart, such wires or pieces of foil *not having been previously brought into contact.* This stream, when received by the dry hands, was exceedingly sharp and painful. A pith-ball, $\frac{1}{4}$ inch in diameter, suspended by a silk thread, vibrated constantly between the opposite poles: 1100 pairs produced this latter effect. If the foot of a gold leaf electrometer was connected with one of the poles, and the hand of another person connected with the other pole brought over the cap of the instrument, even when held at several inches' distance, the leaves struck their sides. Again, if the cap of the same electrometer was connected with either pole of the battery of 1100 pairs, the *opposite pole not being connected with the foot of the instrument,* the leaves continued to strike the sides. This latter is a proof of the great waste occasioned by the imperfect insulation of the cylinders. A much more powerful effect would be produced by a superior insulation:—1600 pairs of cylinders produced the above effects in a much greater degree. In a tolerably well insulated battery every additional ten pairs after the first 100 produce an evidently increased effect; and after 1000 pairs, the next 100 constitute a much greater addition to their power than one might promiscuously have imagined. With 1600 pairs the stream between two wires *not previously brought into contact* was very distinct; the light, however, was not great; the stream was of great intensity, but of small diameter. The method adopted by Mr. Crosse for exhibiting this interesting experiment is this:—he takes a small glass stick, and ties on it with waxed thread, very securely, two wires of platina, with the two extreme ends ready to be plunged into two cups of mercury connected with the opposite poles of the battery: the two other ends of the wires are brought to the distance of about $\frac{1}{100}$ of an inch from each other. The moment the connexion is made with the poles of the battery, a small stream

of fire takes place at the interval between the wires, which may be kept up for many minutes, nor does it appear inclined to cease. This experiment never fails; though with a much greater number of plates, each pair not being separately insulated, it would never succeed.

The light between charcoal points, even with the whole series, was feeble, there was no flame nor even approach to it: the conducting power of the water used in the cells being inadequate to transmit a sufficient current to produce great light and heat, even supposing such current to have been excited. Mr. Crosse has, however, a water battery, consisting of eighty pairs of very large cylinders, which gives very brilliant sparks between two points of charcoal when rubbed together.

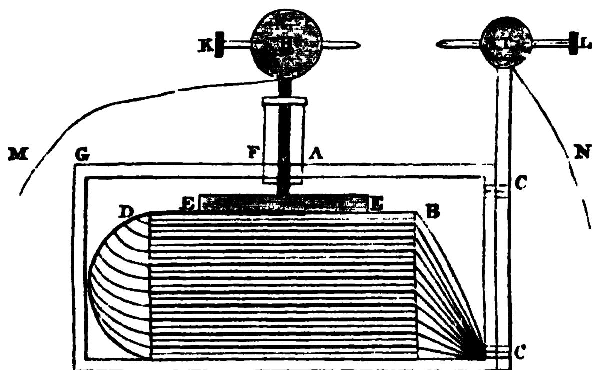
(341) When the opposite poles of the 2,400 pairs were connected with the inner and outer coatings of a large electrical battery, containing 73 feet of surface, a continual charge was kept up, each discharge being attended with a loud report, heard at a considerable distance. Each of these discharges pierced stout letter-paper, and fused a considerable length of silver leaf, which it deflagrated most brilliantly, attended with loud snappings of light, more than a quarter of an inch in length. Platinum wire was fused at the extremity, and the point of a pen-knife was soon demolished. Light substances were attracted a distance of some inches and repelled again: the physiological effects would undoubtedly be exceedingly violent; we have not, however, heard that any person has yet ventured to experience them.

(342) To avoid the trouble of using this large electrical battery, Mr. Crosse constructed one of mica. It is made in the following manner:—Seventeen plates of thin mica, each five inches by four, are coated on both sides to within half an inch of the edge with tin-foil, and let into a box lined with glass, with a glass plate between each mica plate. Slips of tin-foil are pasted to each side of each plate of tin-foil, of which all those connected with the lower ones are brought together at the extremities furthest from the plate, and pasted to one end of the interior of the box; whence, by a tin-foil communication, a connection is made with a brass stem, secured to the outside of the box. This represents what may be called the outer coating of the battery, and is capped with a ball. The remaining strips of tin-foil or those connected with the upper surface of each plate, are brought together at the other end of the interior of the box, and turned back upon the tin-foil or upper part of the top plate. A brass plate, three inches square, is then laid flat upon those combined slips, a cover is fitted on

the box with screws, and a glass tube carrying a brass stem, passing through it and the cover, is fixed in the centre of the cover: such stem being cut at the lower part into a screw, which passes through a female screw cut in a cap, cemented to the lower end of the glass tube within the cover, pressing on the brass plate. The upper part of the stem passes through a cap on the top of a glass tube, and is terminated with a brass ball, and may be termed the inner coating of the battery. By screwing the stem a perfect contact is made between this ball and all the upper surfaces of the mica plates. The two balls are placed on the same level, and a brass wire of $\frac{1}{10}$th inch diameter passes horizontally through the ball of the outer coating, cut into a screw to meet a similar one passing through the opposite ball. These wires are furnished with fine platinum points, and can be brought into contact, or made to recede at pleasure. A micrometer screw may be attached. By means of holes made in the opposite stems, the mica battery may be connected by wires with the opposite poles of a voltaic battery, and the *striking distance* accurately measured between the points.

(343) The whole arrangement will be understood by inspecting Fig. 138. A, is a sectional view of a dry wooden box, lined with

Fig. 138.



glass, containing the plates of covered mica, a plate of window-glass being interposed between each. B, strips of tin-foil a quarter of an inch wide, each of which has one end pasted to the tin-foil *under* each mica plate, and the other end brought to the bottom of the box, and secured together by paste, and attached by a conducting communication of metal to the rod C C. D, similar strips having one end pasted to the tin-foil *over* each mica plate, and the other ends turned back on the upper part of the upper plate. E, E, a thin brass plate three inches square, placed horizontally on the combined ends of the strip. F, a glass tube, capped at each end,

passing through the cover of the box G. Through this tube passes a brass screw, the lower end of which presses on the brass plate E, E, the upper end bearing the brass ball H. I, a brass ball, capping the stem C, C. Both H and I are pierced by the horizontal wires K, L, placed on the same level, cut into screws; and having each a platinum point at one end, and a nut at the other. In each of the upright stems immediately under the balls, is a hole drilled to receive the wires of communication M, N.

(344) The peculiar merits of this apparatus consist in its compactness, and its not being liable to injury from damp. When charged to a certain extent the shock is surprisingly painful, and is equivalent in power to many superficial feet of common coated glass. It is not calculated to be charged to a high intensity, as in such case the thin plates of mica would be pierced. Connected with the water battery, the following results were obtained by Mr. Crosse:—three pairs of cylinders produce light: twenty pairs produce a stream of light: 200 pairs produce a stream of scintillations, by drawing fine iron-wire over the lacquered knob of the mica battery: 300 pairs fire gunpowder: 500 pairs give a smart shock to the dry hands: 1200 pairs give a shock not easily borne,—felt across the breast and shoulders, and cause a constant stream of light to pass between two wires $\frac{1}{8}$ of an inch apart, in an exhausted glass globe of four inches diameter, that globe being faintly but visibly illuminated over the whole of its interior during the experiment: 1600 pairs give a shock perfectly insupportable, which nearly knocked a person down who received it.

(345) Shortly after the above account of the performances of his water-battery was published by Mr. Crosse, the author constructed a series of 500 pairs of cylinders, each equal to a five-inch plate; they were placed in green glass tumblers, insulated with the greatest care, and plaçed in a cupboard furnished with folding doors, to keep out the dust and to diminish evaporation. This battery, which continued in almost uninterrupted action for upwards of two years, gave very powerful shocks when the terminal wires were grasped with the moistened hands, and when the positive wire was held in one hand, and the dry knuckle brought into contact with the binding-screw attached to the negative, a spark was obtained, and a small blister raised on the cuticle; a spark was also obtained between the knuckles of two persons touching, respectively, the positive and negative terminations, and bringing their knuckles into contact. This battery had very slight decomposing power: the emission of gas from platinum points in acidulated water was not so great from the whole series of 500 as from 100, and from 100 not so great as

from 40; this was evidently occasioned by the great resistance which the current had to encounter from the bad conducting power of the water with which the battery was charged; a resistance which it could not overcome, and consequently by far the greater portion of the Electricity generated was checked in its passage, while the small quantity that passed was brought to a high state of intensity. The spark obtained on bringing the ends of the terminal wires into contact was small, but brilliant, and when the ends were placed within the flame of a large candle the phenomena were very beautiful, the carbon being deposited in an arborescent form, and with great rapidity on the positive wire: while on the negative wire it was thrown down in much less quantity, though in a more compact form; occasionally, indeed, filaments started from the latter like the quills on the back of a porcupine. We have seen few more beautiful experiments than this,—it was first made by Mr. Gassiot; the carbon on the *positive* wire assumes the form of every variety of tree and shrub, some particles starting up into the lengthened form of the poplar, whilst others spread laterally, assuming the appearance of fern: in less than a minute the flame of the candle becomes darkened by the quantity of precipitated solid matter, which, as long as both wires remain in the flame, goes on increasing. Occasionally the carbon on the wires comes into contact,—when a bright spark is seen, and the arborescent appearance for a moment vanishes. When the finely divided carbon on the wires is brought into contact *out* of the flame, the spark is exceedingly brilliant, and four or five times as large as the spark from the clean wires, especially when *hot;* a snap also is heard.

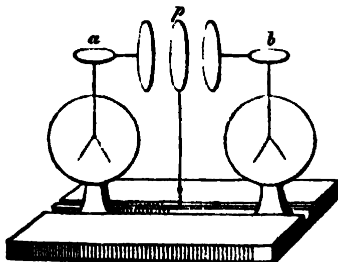
(346) Connected with a mica battery (consisting of twenty plates of mica, each four inches square), 100 pairs scintillated iron wire, and gave a pretty strong shock, the whole series gave a brilliant spark, accompanied by a pretty loud snap, and a powerful shock: it caused brilliant scintillations of iron-wire, deflagrated gold, silver and copper leaf, and exploded gunpowder; it also charged a Leyden battery, containing about twelve square feet of glass, sufficiently high to give unpleasant shocks.

By soldering the terminal wires to two copper plates, about two inches square, and fixing them upright on a turned mahogany frame, under a glass shade, perpetual vibration of a pith-ball $\frac{1}{6}$ of an inch in diameter, suspended by a filament of silk, was kept up rapidly between the plates, placed $\frac{1}{2}$ of an inch apart. The motion of the ball has been kept up unceasingly for a fortnight and three weeks together.

(347) A very extensive arrangement of the water battery is described by Mr. Gassiot (*Phil. Trans.* 1844). It consists of 3520 pairs or series of copper and zinc cylinders, each pair being placed in a separate glass vessel well covered with a coating of lac varnish. The glass cells are placed on slips of glass covered on both sides with a thick coating of lac. The 3520 cells, thus insulated, are placed on forty-four separate oaken boards, also covered with lac varnish, each board carrying 80 cells. The boards or trays slide into a wooden frame, where they are further insulated by resting on pieces of thick plate-glass similarly varnished. Notwithstanding these precautions, the insulation was still imperfect; nor does perfect insulation seem attainable for any lengthened period when such an extended series is employed.

(348) In describing the results obtained with this gigantic battery, Mr. Gassiot considers the *static* and the *dynamic* effects separately. *The static.* On connecting the copper wires from the extreme cells with the plates *a* and *b* of the double electroscope, Fig. 139, the condensing plate *p* being removed, this instantly produces a considerable and steady divergence of the gold leaves; and on applying the usual tests, the plate *b*, connected with the copper extremity, gave signs of vitreous, and *a* connected with the zinc, of resinous Electricity. If *a* was connected with one extremity of the battery, the other extremity being connected or not with the ground, the same general effects occurred; the divergence of the leaves corresponded with the connection, and the leaves of *b* diverged by induction; if in this state *b* was touched, and then removed from the influence of *a*, it was found charged with the opposite Electricity.

Fig. 139.



(349) The assumption of polar tension by the elements constituting the battery *before the circuit was completed* was shown not only by the effect on the leaves of the electroscope when placed

within two or three inches of either end of the battery, or over any of the terminal cells, but by the production of a spark between the terminal wires through the space of $\frac{1}{50}$th of an inch. When the double electroscope (Fig. 139) was included in the circuit, and the discs *a* and *b* closely approximated, the sparks became a stream of fire, which on one occasion were continued uninterruptedly day and night for upwards of five weeks. An experimenter standing on the ground could draw sparks from either terminal.

(350) *Dynamic Effects.*—For testing the presence of what is usually termed the *current*, two trays containing 160 cells of the battery were removed and most carefully insulated; a very delicate galvanometer was interposed between the zinc terminal of one tray, and the copper terminal of the other, but not the slightest deflection of the needle took place, neither was there the least indication of the liberation of iodine when a piece of bibulous paper was saturated with iodide of potassium and substituted for the galvanometer; the inference from which is, that there was no definite chemical action taking place in any cell of the battery, and that the *electric* or *static* effects take place *before, or independently of, the actual development of the chemical effects.*

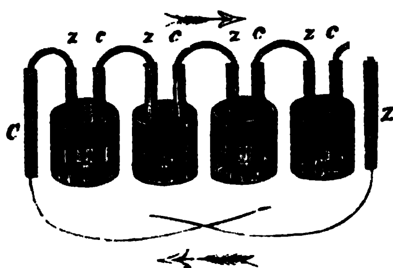
(351) The following instructive experiments were next made:— A copper wire attached to the negative end of the battery was connected with the galvanometer, and this with the plate *a* of the double electroscope (Fig. 139). A platinum wire attached to the positive end rested on a piece of bibulous paper moistened with iodide of potassium, another wire also resting on the paper was connected with the plate *b* of the electroscope. By a mechanical arrangement the plates could be approximated or separated as required. On approximating the plates so as to permit sparks to pass at intervals of about a second, a tremulous motion was imparted to the needle of the galvanometer, but when they were brought so nearly in contact as to permit the discharges to take place in quick succession, the needle was steadily deflected and iodine freely evolved; proving that chemical action was taking place in each cell, and that the current is a collection or accumulation of discharges of Electricity of tension. When 320 cells were employed, the greatest care being taken to insure perfect insulation, not the slightest evidence of any chemical action taking place in the cells could be obtained previous to completing the circuit, although there was sufficient intensity to elicit sparks through $\frac{1}{100}$th of an inch.

(352) The following conclusions are deduced by Mr. Gassiot from his experiment with this extraordinary battery. 1st. That the elements constituting the voltaic battery assume *polar tension*

before the circuit is complete. 2nd. That this tension when exalted by a series of pairs is such, that sparks will pass between the terminals of the battery *before* their actual contact. 3rd. That these static effects precede and are independent of the completion of the voltaic circuit, as well as of any *perceptible* development of chemical or dynamic action. 4th. That the current may be regarded as a series of discharges of Electricity of tension succeeding each other with infinite rapidity. 5th. That the rise of tension in a battery occupies a measurable portion of time. 6th. That the *static* effects elicited from a voltaic series are direct evidence of the first step towards chemical combination or dynamic action.

(353) It is easy to see that many inconveniences must attach to the pile of Volta, when the plates are numerous: in addition to the trouble of building it up, it is frequently rendered comparatively inactive by the moisture pressed out of the lower part by the weight of the upper: hence, the substitution of troughs and other arrangements. The most simple of these is Volta's "Couronne des tasses," shown in Fig. 140, which consists in a row of small glasses or cups, containing very diluted sulphuric acid, in each of which is placed a small plate of copper, about two inches square, and another similar sized plate of zinc, not touching each other, but so constructed that the zinc of the first glass may be in metallic communication with the copper of the second, the zinc of the second with the copper of the third, and so on throughout the series. By this arrangement, when glasses are employed, we can see what is going on in each cell: and if the zinc plates be amalgamated it will be observed that when the wires are connected, and consequently when a current is passing, all the copper surfaces rapidly evolve hydrogen gas, while the solution of the zinc proceeds quietly; but, that when the connection between the extreme plates is broken, the evolution of gas ceases. Eighteen or twenty pairs of plates will decompose acidulated water rapidly, and thirty will give a distinct shock to the moistened hands.

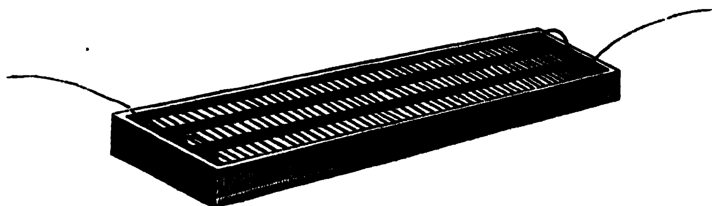
Fig. 140.



(354) Another arrangement of the plates is shown in Fig. 141, where they are represented as fixed in pairs into a trough of wood: this constitutes Cruickshank's battery. It is very convenient when solution of sulphate of copper is used as the exciting agent, which, as

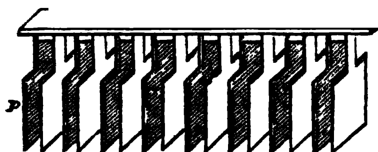
Dr. Fyfe has shown (*L. & E. Phil. Mag.* vol. xi. p. 145), increases the electro-chemical intensity of the electric current, as compared

Fig. 141.



with that evolved by dilute sulphuric acid in the proportion of seventy-two to sixteen. An important modification was that suggested by the late Dr. Babington, and shown in Fig. 142: the plates

Fig. 142.

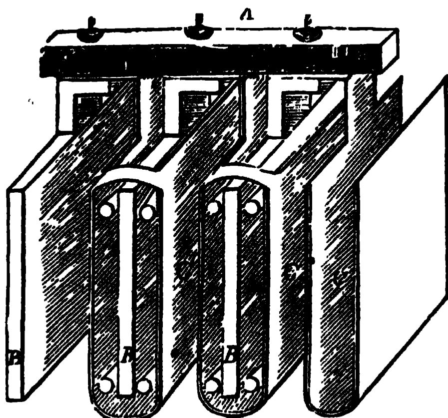


of copper and zinc, usually about four inches square, are united together in pairs by soldering at one point only; the trough in which they are immersed is made of earthenware, and divided into 10 or 12 equal portions. The plates are attached to a strip of wood, and so arranged that each pair shall enlose a partition between them: by this means the whole set may be lifted at once into or out of the cells; and thus, while the fluid remains in the trough, the action of the plates may be suspended at pleasure, and when corroded, easily replaced. The piece of wood to which the plates are attached should be well dried, and then varnished, in order to render it a non-conductor of Electricity. When several of these troughs are to be united together, it is necessary to be cautious in their arrangement, as a single trough *reversed* will very materially diminish the general effect. Care must also be taken to insure perfect communication between the several plates. A battery of two thousand double plates, on this plan, was constructed several years ago for the Royal Institution; the surface was one hundred and twenty-eight thousand square inches, and its power immense.

(355) A great improvement in the construction of voltaic batteries was made by Dr. Wollaston, in 1815. It consisted in doubling the copper plate, so as to oppose it to both surfaces of the zinc, as shown

in Fig. 143. *A* represents the bar of wood to which the plates are screwed; *B B B* the zinc plates connected with the copper plates *C C C*, which are doubled over the zinc plates. Contact of the surfaces is prevented by pieces of wood or cork placed between them. Ten or twelve troughs, on this construction, form a very efficient voltaic battery.

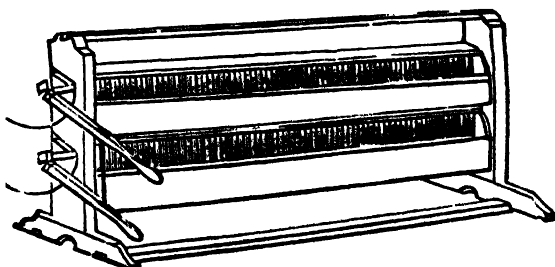
Fig. 143.



It appears, from the experiments of Mr. Christopher Binks (*L. & E. Phil. Mag.* for July, 1837), that a still further extension of the copper would be attended with a considerable increase of power. He remarks that whatever may be the care taken to procure two plates of zinc of an uniform size and thickness, and however alike the attendant circumstances may be, no two couples will be found to give the same results in the same time when associated with corresponding copper plates, and acted on by acids in the usual way. While one plate will lose perhaps ten grains; another, apparently similar, will lose five or six grains; and another, fifteen or sixteen in the same time: these differences he finds to be independent of accidental differences in the distances of the plates from one another: zinc plates he also finds to lose less the first time of immersion than during the second and third.

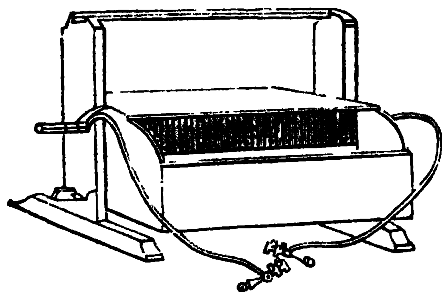
(356) The arrangement shown in Fig. 144 is that of Professor Hare, of Philadelphia. It combines the advantages of the *compound*

Fig. 144.



trough and the calorimotor or deflagrator. A voltaic series fixed in a trough is combined with another trough destitute of plates, and of a capacity sufficient to hold all the acid necessary for an ample charge. The trough containing the series is joined to the other lengthwise, edge to edge; so that, when the sides of the one are vertical, those of the other must be horizontal. The advantage of this is, that by a partial revolution of the two troughs, thus united, upon pivots which support them at the ends, any fluid which may be in one trough must flow into the other, and, reversing the movement, must flow back again. The galvanic series being placed in one of the troughs, and the acid in the other, by a movement such as has been described, the plates may all be instantaneously subjected to the acid or removed from it. The pivots are made of iron, coated with brass or copper, as less liable to oxidizement. A metallic communication is made between the coating of the pivots and the galvanic series within. In order to produce a connection between one recipient of this description and another, it is only necessary to allow a pivot of each trough to revolve on one of the two ends of a strap of sheet copper. To connect with the termination of the series the leaden rods (to which are soldered the vices or spring forceps for holding the substances to be exposed to the deflagrating power), one end of each is soldered to a piece of sheet copper. The pieces of copper thus soldered to the leaden rods are then to be placed under the pivots, which are, of course, to be connected with the termination of the series; the last-mentioned connection is conveniently made by

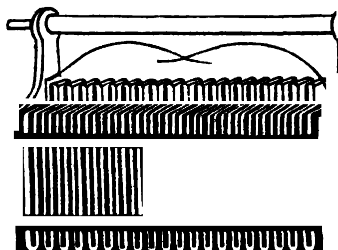
Fig. 145.



means of straps of copper, severally soldered to the pivots and the poles of the series, and screwed together by a hand-vice. Each pair consists of a copper and zinc plate, soldered together at the upper edge, where the copper is made to embrace the edge of the zinc. The three remaining edges are made to enter a groove in the wood,

being secured therein by cement. For each inch in the length of the trough there are three pairs. In the series represented in Fig. 144 there are seven hundred pairs of seven inches by three, and in that shown in Fig. 145, one hundred pairs of fourteen inches by eight. The latter will deflagrate wires too large to be ignited by the former, but is less powerful in producing a jet of flame between two charcoal points, or in giving a shock. Dr. Hare exhibited two of these batteries at the meeting of the British Association at Bristol in 1836. Their power was very great in proportion to their size.

Fig. 146.

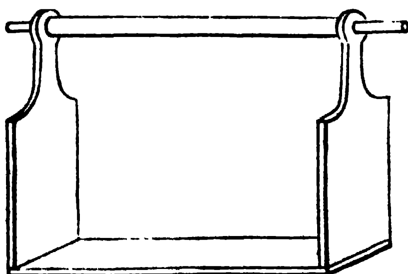


(357) A useful arrangement of copper and zinc plates for a voltaic battery, the contrivance of J. A. Van Melsen, of Maestricht, is shown in Fig. 146. The copper soldered to the zinc in each pair envelopes the zinc of the following pair, so as to be exposed to the two surfaces of this plate, but without being in contact with it. It differs from Wollaston's pile in having the metallic plates much nearer to each other: they are only about $\frac{1}{10}$ inch apart, and are maintained thus by small pieces of cork interposed between the plates of zinc and those of copper, whilst the plates of copper of the consecutive elements are separated by squares of glass of the same size as the plates. Fig. 147 represents two elements of the series. All the pairs are placed in a kind of wooden frame, Fig. 148, carefully varnished, in which they are

Fig. 147.



Fig. 148.



easily retained without its being necessary to attach them by screws to a bar of wood, as is the case in the Wollaston combination. This arrangement presents the additional advantage of greatly facilitating the taking to pieces of the elements. The pairs united in the frame are at once immersed into the acidulated liquid contained in the trough: the plates of zinc are carefully amalgamated. Van Melsen describes a battery* on this plan, which he constructed for the Maestricht University, consisting of 52 pairs, of which the plates of zinc are $6\frac{1}{2}$ inches wide, and $7\frac{7}{8}$ inches high. By its means a platinum wire $\frac{1}{30}$ of an inch thick, and $17\frac{3}{4}$ inches long, was reduced to incandescence with an extraordinary brilliancy, and fell into seven pieces, at the extremities of which the melted metal arranged itself in globules. A silver wire $\frac{1}{30}$ of an inch thick, and $15\frac{3}{4}$ inches long, became intensely red, and fell into fragments. An iron wire $\frac{1}{20}$ of an inch thick, and $15\frac{3}{4}$ inches long, was speedily brought to the most vivid state of ignition, and was reduced into four pieces, in which, in many places, the melted iron was gathered into large globules. At the period of this latter experiment the battery had already been a long time in action, and was much weakened. When the battery was first excited, in order to produce a spark, the two slips of copper which serve as conductors were brought into contact. The parts in contact became immediately soldered together, so that it was necessary to employ a certain effort to separate them.

(358) In a series of papers in the Philosophical Transactions for 1836, Professor Daniell describes his "constant" battery, and the circumstances which led to its adoption. It has been remarked in the former part of this chapter that the evolution of hydrogen gas from the negative metallic surface in the common galvanic battery, greatly interferes with the development of *available* Electricity, for a considerable portion of the Electricity that is actually generated is probably spent in giving a gaseous form to the hydrogen of the decomposed water. But besides this, Mr. Daniell found that not only were the oxides of copper and zinc reduced by the *nascent* hydrogen at the moment of its formation, when salts of these metals were purposely dissolved in the fluid of the cells of the battery; but the oxide of zinc itself, formed at the generating plates, *was reduced* at the conducting plates, which became ultimately so incrusted with metallic zinc as entirely to destroy the circulating force. The variations and progressive decline of the power of the ordinary voltaic battery are thus accounted for, since the transfer of the electro-positive metal must eventually cause two zinc surfaces to become opposed to each

* Proceedings of the Electrical Society, p. 186.

other, the use therefore of the nitric acid in the battery charge is to remove the hydrogen by combination. Since, therefore, the hydrogen has a two-fold injurious tendency, its absence altogether becomes a desirable object to effect. In a battery constructed by Mr. Warren De la Rue, this was done by the employment of sulphate of copper as the exciting agent, and in the arrangement of Professor Daniell the same is accomplished, but under circumstances rather different, as will presently appear.

Fig. 149.

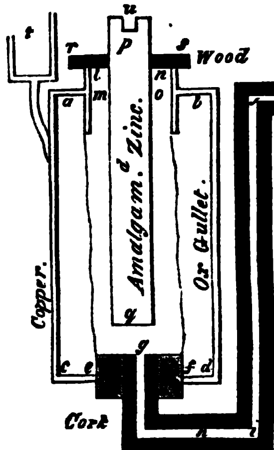


Fig. 149 represents a section of one of the cells of Daniell's original "sustaining" or "constant" battery; *a b c d* is a cylinder of copper, six inches high and three and a half inches wide; it is open at the top *a b*, but closed at the bottom, except a collar *e f*, one inch and a half wide, intended for the reception of a cork, into which a glass syphon tube *g h i j k* is fitted. On the top *a b*, a copper collar, corresponding with the one at bottom, rests by two horizontal arms. Previously to fixing the cork syphon tube in its place, a membranous tube, formed of part of the gullet of an ox, is drawn through the lower collar *e f*, and fastened with twine to the upper, *l m n o*, and when tightly fixed by the cork below, forming an internal cavity to the cell communicating to the syphon tube, in such a way as, that when filled with any liquid to the level *m o*, any addition causes it to flow out at the aperture *k*. In this state, for any number of drops allowed to fall into the top of the cavity, an equal number are discharged from the bottom *a*, at the top of the zinc rod. Various connections of the copper and zinc of the different cells, may be made by means of wires proceeding from one to the other. In the construction of this battery, Mr. Daniell availed himself of the power of reducing the surface of the generating plates to a minimum. The effective surface of one of the amalgamated zinc rods, being less than ten square inches, whilst the internal surface of the copper cylinder to which it is opposed is nearly seventy-two inches. His principal objects were to remove out of the circuit the oxide of zinc, (which has been proved to be so injurious to the action of the common battery,) as fast as the solution is formed, and to absorb the hydrogen evolved upon the copper, without the precipitation of any substance that might deteriorate the latter.

(359) The first is completely effected by the suspension of the zinc rod in the interior membranous cell, into which the fresh acidulated water is allowed slowly to drop, from a funnel suspended over it, and the aperture of which is adjusted for the purpose; whilst the heavier solution of the oxide is withdrawn from the bottom at an equal rate by the syphon tube. When both the exterior and interior cavities of the cell were charged with the same diluted acid, and connection made between the zinc and the copper, by means of a fine platinum wire, $\frac{1}{100}$ of an inch in diameter, he found that the wire became red hot, and that the wet membrane presented no obstruction to the passage of the current.

The second object is obtained by charging the exterior space surrounding the membrane, with a saturated solution of sulphate of copper, instead of diluted acid; upon completing the circuit the current passed freely through this solution; no hydrogen made its appearance on the conducting plate; but a beautiful pink coating of pure copper was deposited upon it, and thus perpetually renewed its surface.

When the whole battery was properly arranged and charged in this manner, no evolution of gas took place from the generating or conducting plates, either before or after the connexions were complete; but when a voltameter was included in the circuit, its action was found to be very energetic. It was also much more steady and permanent than that of the ordinary battery, but still there was a gradual but very slow decline, which Mr. Daniell traced at length to the weakening of the saline solution, by the precipitation of the copper, and consequent decline of its conducting power.

(360) To obviate this defect, some solid sulphate of copper was suspended in muslin bags, which just dipped below the surface of the solution in the cylinders, which, gradually dissolving as the precipitation proceeded, kept it in a state of saturation. This expedient fully answered the purpose, and Mr. Daniell found the current perfectly steady for six hours together. This arrangement he subsequently improved, by placing the salt in a perforated colander of copper, fixed to the copper collar.

Fig. 150.

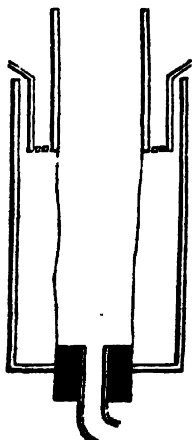


Fig. 150 represents a section of this additional arrangement. The colander with its central collar, rests by a small ledge upon the rim of the cylinder. The membrane is drawn through the collar, and turning over its edge is fastened with twine. After this alteration, the effective

length of the zinc rods exposed to the action of the acid was found to be no more than four inches and a quarter. (*Philosophical Transactions*, 1836.)

(361) The advantages of this battery over those of the previous construction are very great; it secures a total absence of any wear in the copper; it requires no nitric acid, but the substitution of materials of great cheapness, namely, sulphate of copper and oil of vitriol; it enables us to get rid of all local action, by the facility it affords of applying amalgamated zinc, and allows the replacement of zinc rods at a very trifling expense; it secures the total absence of any annoying fumes; and, lastly, it produces a perfectly equal and steady current of Electricity for many hours together.

With a battery of twenty cells arranged in a single series, twelve cubic inches of mixed oxygen and hydrogen gases may be collected from a voltameter in every five minutes of action, and when they are first connected in pairs, and afterwards in a series of ten, the quantity amounts to seventeen cubic inches. Eight inches of platinum wire, $\frac{1}{150}$ of an inch in diameter, may be kept permanently red hot by the same arrangement, and the spark between charcoal points is very large and brilliant.

Mr. Daniell even made it the source of the purest oxygen for laboratory purposes. To this end he constructed an *oxygen cell*, by substituting a plate of platinum for the rod of zinc, enclosing it in the membranous tube, which is closed at the upper end by a glass tube, bent in a proper form to deliver the disengaged gas, under a receiver. In this arrangement the hydrogen is absorbed as before, by the oxide of copper, but the oxygen, to the amount of eighty cubic inches per hour, is given off from the platinum.

Fig. 151.



(362) Fig. 151 represents a single cell of the constant battery, a cylindrical vessel of porous earth being substituted for the bladder diaphragm, which proved very inconvenient on account of its becoming rapidly corroded, and pierced by the sharp edges of the crystals of metallic copper, deposited on the copper plate. These porous jars were, it seems, first employed by Mr. Dancer,* of Liverpool, and they are now composed of the thinnest unglazed biscuit ware, a most excellent material. The battery, shown in Fig. 151, consists of a cylinder of copper, containing a tube of biscuit ware, which has a solid rod of zinc supported in its centre; the cylinder is furnished with a perforated shelf, upon which a supply of crystals of sulphate of copper is placed, so that the battery being once charged, will maintain an equal action for many hours.

* Golding Bird's Elements of Natural Philosophy.

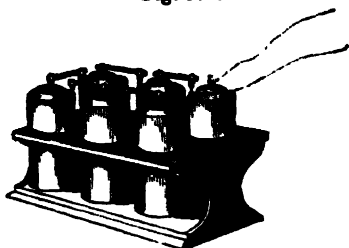
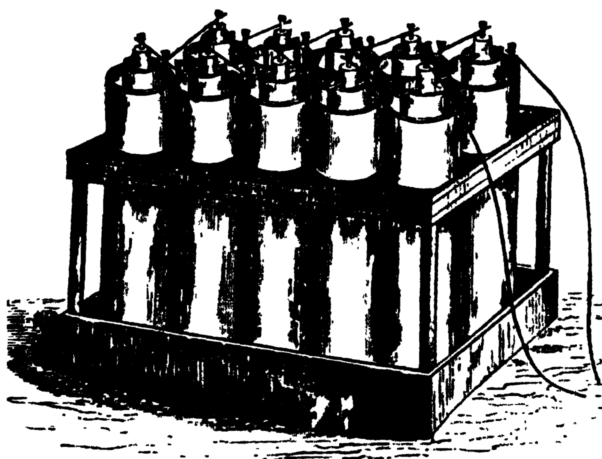


Fig. 152.

Fig. 152 represents a set of six of the above batteries, and Fig. 153 a set of ten large ones, the copper cylinders being eighteen or twenty-one inches high, with zinc rods, and porous earthen tubes in proportion. This forms a powerful voltaic arrangement, evolving eight or ten cubic inches of oxygen and hydrogen gases in the voltameter per minute, and heating to redness twelve or fourteen inches of fine iron wire.

A series of thirty cells of the smaller size, six inches high, and three and a half inches in diameter, forms a very efficient battery for the lecture table; it heats from eighteen inches to two feet of iron-wire, deflagrates mercury most brilliantly, and burns metallic leaves

Fig. 153.



vividly. The cells of the sustaining battery must be plentifully supplied with sulphuric acid, without which the power is but feeble. Mr. Daniell recommends a mixture of eight parts of water, and one of oil of vitriol, which has been saturated with sulphate of copper, for the copper cell, the internal tube being filled with the same acid mixture without the copper. The porous cells should be well soaked in dilute sulphuric acid for an hour or two before being used; and after their removal from the battery they should be repeatedly rinsed, or allowed to soak for some time in warm water, to dissolve out all the metallic salt from their pores. If this be not attended to they will be soon destroyed.

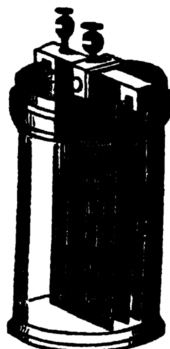
(363) It was found by Mr. Daniell (*Transactions of the Royal Society*, May 30th, 1819) that the action of the constant battery is by no means proportional to the surfaces of the conducting hemispheres, but approximates to the simple ratio of their diameters; and hence, he concludes that the circulating force of both simple and compound voltaic circuits increases with the surface of the conducting plates surrounding the active centres. On these principles he constructed a constant battery, consisting of seventy cells, in a single series, which gave between charcoal points, separated to a distance of three quarters of an inch, a flame of considerable volume, forming a continuous arch, and emitting radiant heat and light of the greatest intensity. The latter, indeed, proved highly injurious to the eyes of spectators, in which, although they were protected by grey glasses, of double thickness, a state of very active inflammation was induced; the whole face of Mr. Daniell became scorched and inflamed, as if it had been exposed for many hours to a bright midsummer's sun. The rays, when reflected from an imperfect parabolic metallic mirror in a lantern, and collected into a focus by a glass lens, readily burnt a hole in a paper at a distance of many feet from their source. The heat was quite intolerable to the hand held near the lantern. Paper steeped in nitrate of silver, and afterwards dried, was speedily turned brown by this light; and when a piece of fine wire-gauze was held before it, the pattern of the latter appeared in white lines corresponding to the parts which it protected. The phenomenon of the transfer of the charcoal from one electrode to the other, noticed by Dr. Hare, but first observed by Professor Silliman, was abundantly apparent; taking place from the *zincode* (or positive pole) to the *platinode* (or negative pole). The arch of flame between the electrodes was attracted or repelled by the poles of a magnet, according as the one or other pole was held above or below it; and the repulsion was at times so great as to extinguish the flame. When the flame was drawn from the pole of the magnet itself, including the circuit, it rotated in a beautiful manner.

The heating power of this battery was so great as to fuse with the utmost readiness a bar of platinum, one-eighth of an inch square; and the most infusible metals, such as pure rhodium, iridium, titanium, the native alloy of iridium and osmium, and the native ore of platinum, placed in a cavity, scooped out of a piece of hard carbon, freely melted in considerable quantities.

(364) Mr. Gassiot afterwards, with the view of ascertaining the possibility of obtaining a spark before the circuit of the voltaic battery is completed, prepared first 160, and then 320 series of the constant battery in half-pint porcelain cells, excited with solutions of

sulphate of copper and muriate of soda; but although the effects, after the contact had been completed, were exceedingly brilliant, not the slightest spark could be obtained. He mentions in his paper (*Phil. Trans.* 1840), that having been present at the experiments of Professor Daniell, above alluded to, he was induced to prepare 100 series of the large constant battery; but although this powerful apparatus was used under every advantage, and the other effects produced were in every respect in accordance with the extent of the elements employed, still no spark could be obtained until the circuit was completed: even a *single fold of a silk handkerchief*, or a piece of dry tissue paper, was sufficient to insulate the power of the battery, though after the circuit had been once completed, it fused titanium, and heated sixteen feet four inches of No. 20 platinum wire.

Fig 154.

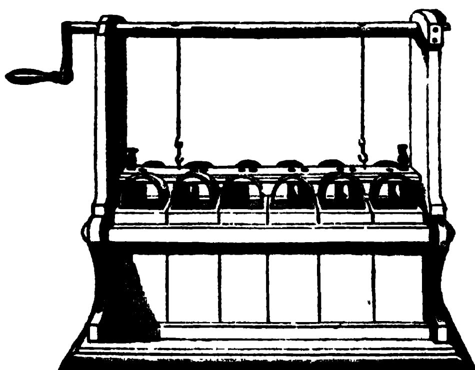


(365) Fig. 154 represents a single cell of Mr. Smee's voltaic arrangement, which, considering its advantages to arise from a mechanical help to the evolution of the hydrogen gas, he calls the *chemico-mechanical* battery. The circumstances which led the author to the construction of this admirable battery, are detailed in a paper inserted in the 16th volume of the *L. and E. Phil. Mag.* He observes, that "the influence of different conditions of surfaces is a subject which has escaped all experimenters, which is singular, as many must have noticed that in a circuit the greatest quantity of gas is given off at the corners, edges, and points. Following this hint, a piece of spongy platinum, consisting as it does of an infinity of points, was placed in contact with amalgamated zinc, when a most violent action ensued, so that but little doubt could be entertained of its forming a very powerful battery. The fragile nature of this material precludes it from being thus used, and therefore it was determined that another piece of platinum should be coated with the finely divided metal. This experiment was attended with a similar good result, and the energy of the metal thus coated was found to be surprising. After a variety of experiments, Mr. Smee found that silver plates were preferable for receiving the precipitated platinum, and he gives the following directions for preparing them:—"Each piece of metal is to be placed in water, to which a little dilute sulphuric acid and nitro-muriate of platinum is to be added. A simple current is then to be formed by zinc placed in a porous tube with dilute acid, when, after the lapse of a short time, the metal will be coated with a fine black powder of

metallic platinum. The trouble of this operation is most trifling, only requiring a little time after the arrangement of the apparatus, which takes even less than the description." The cost is about sixpence a plate, of 4 inches each way, or 32 inches of surface. It is necessary to make the surface of the silver rough, by brushing it over with a little strong nitric acid, which gives it instantly a frosted appearance, and after being washed it is ready for the platinizing process; but the finely divided platinum does not adhere firmly to very smooth metals.

(366) The arrangement of the platinized silver battery will be immediately understood from the figure. A piece of the platinized silver has a beam of wood fixed on the top to prevent contact with the zinc, and is furnished with a binding-screw. A strip of stout and well amalgamated zinc, varying from one half to the entire width of the silver, is placed on each side of the wood, and both are held in their place by a binding-screw sufficiently wide to embrace the zincs and the wood. This arrangement is immersed in a jar or glass, containing dilute sulphuric acid (1 oil of vitriol and 7 water), and not the slightest effect is produced till a communication is made between the metals, when it instantly hisses and bubbles, and an active voltaic battery is obtained. For intensity effects it may be arranged as an ordinary Wollaston's battery with advantage, as shown in Fig. 155; the plates being raised from, and immersed into, the cells by

Fig. 155.



means of a winding apparatus; or a series of glass tumblers may be connected together; 10 or 12 form a very efficient battery, having a very elegant appearance, and well adapted for the lecture table, as the action in each cell may thus be very clearly seen. On account of the rapid removal of the hydrogen gas, there is, in this form of galvanic battery, but little tendency for the zinc to be deposited in a

metallic state upon the negative metal; nevertheless, when it is required in action for a long period, it may be advisable to separate the metals by a porous earthenware vessel; or what answers the purpose equally well, by a thick paper bag, the joinings of which must be effected by shell-lac dissolved in alcohol. By these means the sulphate of zinc is retained on the zinc side of the battery. It may also be arranged as a circular disc battery, or as a Cruickshank, each cell being divided or not by a flat porous diaphragm; but whatever arrangement is adopted, the closer the zinc is brought to the platinized metal the greater will be the power.

In using the chemico-mechanical battery, it is important that no salt of copper, lead, or other base metal, be dropped into the exciting liquid, as by that means there is a chance of getting a deposit on the negative metal, copper in particular is apt to get precipitated, in which case the platinized silver should be immersed in dilute sulphuric acid, to which a few drops of nitro-muriate of platinum should be previously added, by this process the baser metals are dissolved, and metallic platinum thrown down.

The platinized silver battery has become a great favourite with the public; it is simple in its construction, remarkably manageable in its applications, and elegant in its appearance. It is soon set in action, and as quickly cleaned and put aside; and although it has not the constancy of the admirable battery of Daniell, or the wonderful energy of the battery of Grove, it may be kept in active operation for six, eight, ten, or more days, when a sufficiency of acid is supplied to it; hence, its extensive application in the art of electro-metallurgy.

(367) In a paper read before the Royal Academy of Sciences of Paris, April 15, 1839, Mr. Grove alludes to the powerful development of Electricity which would be occasioned by the combination of four elements instead of three; as, by this means, we should have nearly the sum of chemical affinities instead of their difference. He then describes some experiments which he considers as possessing a high interest, as they prove a well-known chemical phenomenon to depend on Electricity, and thus tighten the link which binds these two sciences; and they led to the discovery of a voltaic combination much more powerful than any previously known. Gold-leaf is well-known to be unaffected by either nitric or by muriatic acid *alone*, though in a mixture of the two acids the metal dissolves. Mr. Grove cemented the bowl of a tobacco-pipe (Fig. 156) into the bottom of a wine-glass; into this he poured pure nitric acid, while the wine-glass was filled with muriatic acid to the same level; in this latter acid two strips of gold-leaf were allowed to remain for an hour,

at the end of which time they were found as bright as when first immersed. A gold wire was now made to touch the nitric acid and the extremity of one of the strips of gold leaf; this was instantly dissolved while the other strip remained unaltered. Two strips of gold-leaf were afterwards made the electrodes of a single pair of voltaic metals in muriatic acid; the acid was decomposed, and the positive electrode was dissolved.

(368) The action is evidently this: as soon as the electric current is established, both the acids are decomposed, the hydrogen of the muriatic acid unites with the oxygen of the nitric, and the chlorine attacks the gold. By the test of the galvanometer, the gold which was dissolved was found to represent the zinc of an ordinary voltaic combination; and reasoning on the phenomena, it occurred to Mr. Grove to substitute zinc for the gold; and on submitting it to the test of experiment, he found that a single pair, composed of a strip of amalgamated zinc, an inch long and a quarter of an inch wide, a cylinder of platinum, three quarters of an inch high, with a tobacco-pipe bowl, and an egg-cup, readily decomposed acidulated water. This little elementary battery is shown in Fig. 156. He then substituted for the muriatic acid caustic potash, and found the action equally powerful; then, sulphuric acid, with four or five times its volume of water; and, although with this the intensity was a little diminished, yet, from its exercising less local action on the zinc, he was eventually induced to give it the preference.

Mr. Grove then constructed a small battery, of a circular shape, consisting of seven liqueur glasses and seven pipe bowls: the diameter was four inches, the height one inch and a quarter. This pocket battery gave about a cubic inch of mixed gases in two minutes.

Fig. 156.

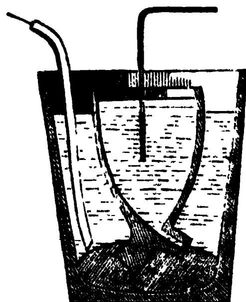


Fig. 157.

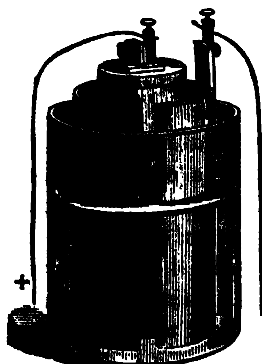


Fig. 157 represents a single cell of the nitric acid battery, the zinc

cylinder Z, open at both ends and divided longitudinally, is plunged into a glass or stoneware vessel containing dilute sulphuric acid, and the platinum plate P, Fig. 158, which is corrugated to give it greater surface, is immersed in a porous cell containing common nitric acid.

The sectional diagram, Fig. 159, exhibits the mode of fitting

Fig. 158.

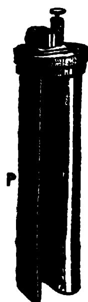
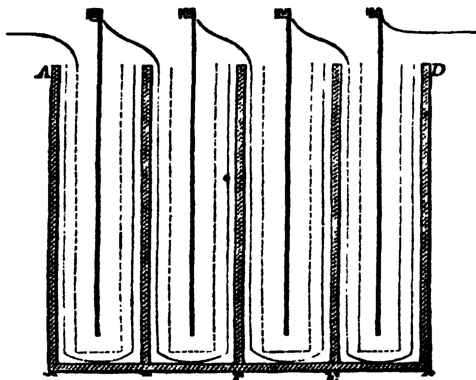


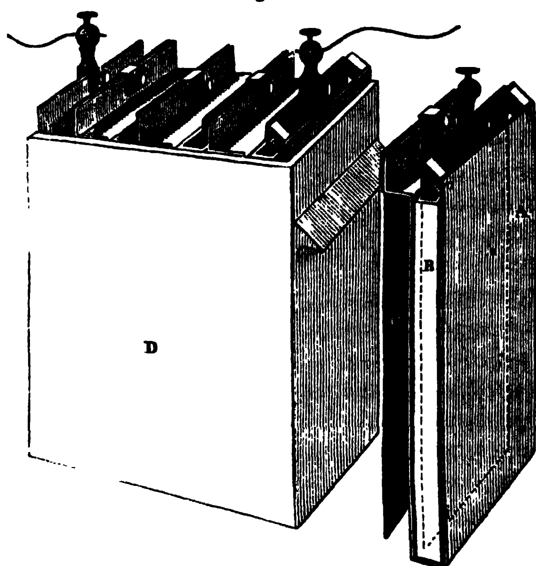
Fig. 159.



up four pairs of zinc and platinum foil plates, as recommended by the inventor. *A B C D* is a trough of stoneware or glass, with partitions *E E E* dividing it into four acid proof cells. The dotted lines represent four porous vessels, of a parallelopiped shape, so much narrower than the cells as to allow the liquid which they contain to be double the volume of that which surrounds them; the four dark central lines represent the zinc plates, and the five lines which curve under the porous vessels the sheets of platinum foil, which are fixed to the zinc by little clamp screws. Common rolled zinc, about one-thirtieth of an inch thick and well amalgamated, may be employed. On the zinc side, or into the porous vessels, is poured a solution of either muriatic acid diluted with from two to two-and-a-half water, or, if the battery be intended to remain a long time in action, of sulphuric acid, diluted with four to five water; and on the platinum side, concentrated nitro-sulphuric acid, formed by previous mixture of equal measures of the two acids. The apparatus should be provided with a cover containing lime, to absorb the nitrous vapour. Fig. 160 represents a battery of four cells arranged in series, and the first set of plates, removed from the porcelain trough D, showing very clearly the arrangement. A *a* is the bent zinc plate, B the insulated platinum plate in its porous cell, C the next platinum plate connected by means of a binding screw with the zinc at *a*.

(369) On the evening of March 13, 1840, Mr. Grove delivered at the Royal Institution a lecture on voltaic reaction and polarization,

Fig. 160.



and afterwards exhibited two batteries, constructed as above described. They were charged some time previously to the lecture; and up to the period of its conclusion, remained in perfect inactivity, until the circuit was completed. One of these was arranged as a series of five plates, and contained altogether about four square feet of platinum foil: with this the mixed gases were liberated from water, at the surprising rate of 110 cubic inches per minute. A sheet of platinum, one inch wide and twelve inches long, was heated in the open air through its whole extent, and the usual class of effects was produced in corresponding proportion. With the other arrangement, consisting of fifty plates, of two inches by four, arranged in single series, a voluminous flame of one inch and a quarter long was exhibited between charcoal points, which showed beautifully the magnetic properties of the voltaic arc; and bars of different metals were instantly run into globules, and dissipated in oxide. These surprising effects were produced, it must be remembered, by a battery which did not cover a space of sixteen inches square, and was only four inches high. In a paper inserted in the 16th vol. of the *L. and E. Phil. Mag.*, Mr. Grove describes a battery of thirty-six elements, each consisting of a square inch of platinum foil and zinc, and charged with concentrated nitric and diluted sulphuric acid, of each of which it took a pound, so that for the expense of about a shilling he could experiment for eight or nine hours without

fresh charge, with a battery which gave between charcoal points an arc of light 0·4 of an inch long. Professor Jacobi states, that he has readily fused iridium, with a nitric acid battery, after it has been at work a whole day. With an arrangement of 100 pairs of this battery, the performances are brilliant in the extreme: the flame between charcoal terminals is exceedingly voluminous, and so brilliant as to be almost insupportable to the naked eye; upwards of two feet of stout iron wire are heated to whiteness, and ultimately fused, and sulphuret of antimony is decomposed, and the metal brilliantly deflagrated.

(370) The following explanation of the superior power of this battery is given by Mr. Grove (*L. and E. Phil. Mag.*, vol. xv., p. 289). "In the common zinc and copper battery the resulting power is as the affinity of the anion* of the generating electrolyte for zinc, minus its affinity for copper. In the common constant battery, it is as the same affinity plus that of oxygen for hydrogen, minus that of oxygen for copper: in the combination in question, the same order of positive affinities minus that of oxygen for azote. As nitric acid parts with its oxygen more readily than sulphate of copper, resistance is lessened, and the power correlatively increased. With regard to the second material question, that of cross precipitation; in the common combination, zinc is precipitated on the negative metal, and a powerful opposed force created: in the constant battery, copper is precipitated, and the opposition is lessened: in this there is no precipitation, and consequently no counteraction.

"If the operation of the battery be watched, the nitric acid changes colour, assuming first a yellow, then a green, then a blue colour, and lastly, becomes aqueous; after some time nitrous gas, and ultimately hydrogen, is evolved from the surface of the platinum."

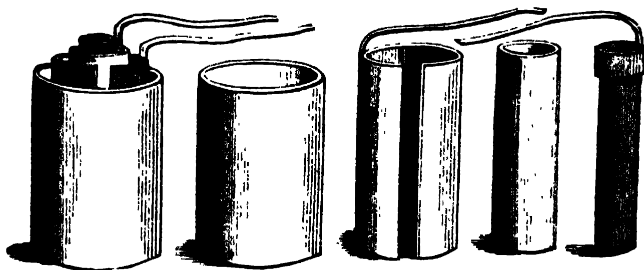
In the paper from which the above extract is taken, Mr. Grove describes an arrangement of his battery, which, *theoretically*, should evolve 218 cubic inches of mixed gases per minute, or nearly seven and a half cubic feet per hour; and, should the period arrive when Electricity shall supersede steam, and become a means of locomotion, the form of battery which he describes would probably be the best that could be devised. The excellent method of economising space, viz., by crimping the negative metal, was proposed by Mr. Spencer, of Liverpool: by this means, in a given space, the surface may be doubled without increasing the mean distance between the metals.

(371) A substitution of carbon for platinum in the nitric acid bat-

* The terms *anion*, *cation*, *electrolyte*, &c., will be explained in the next chapter.

tery was introduced by M. Bunsen (*Archives de l'Electricité*, No. 7, 103; *Pogg. Ann.* vol. lv., p. 265). It had often been attempted to use for this purpose, graphite, and gas carbon, but the excessive cohesion of these substances, the difficulty experienced in working them, and still more the impossibility of making them into pieces of a given form and dimensions, prevented their adoption. Professor Bunsen, however, succeeded in surmounting the difficulty, by heating together in proper proportions, a mixture of well-baked coke and pit coal, both in fine powder. The mixture is heated over a moderate charcoal fire, in sheet iron moulds, or in the form of hollow cylinders, by introducing within the iron mould a cylindrical wooden box, and filling with the mixture the interval existing between the two walls. To render the porous mass compact, it is plunged into a concentrated solution of sugar, and then dried until the sugar has acquired a solid consistence. It is afterwards exposed, for several hours, to the action of a very intense white heat in a covered vessel. If discs are required they are cut out of a cubical block of the prepared carbon, and polished on a plate of grey stone. Bunsen's battery has the cylindrical form of Daniell's, Fig. 161. Each carbon cylinder carries at

Fig. 161.



its upper part a collar of copper, carrying a strip of the same metal, by which it can be metallically connected by means of pincers with another metal strap soldered to the zinc cylinder in the adjoining cell; care must, however, be taken that the carbon cylinder is sufficiently high, that the part which carries the copper ring shall rise above the glass vessel, and consequently shall in no way come into contact with the nitric acid. It is difficult, however, to prevent this in consequence of the porosity of the carbon, and the ring must therefore be removed and washed every time the battery is used. The porous earthen cell is placed within the carbon cylinder, in which is contained the zinc element. A modification of this battery

was contrived by M. Bonijol (*De la Rive's Treatise*, vol. i. p. 46, *Walker's translation*). He employs solid cylinders of carbon, in the tops of which are inserted stout copper rods covered in with a coating of wax, which prevents the nitric acid from ascending as far as the copper. In this arrangement the amalgamated zinc cylinder is outside the carbon, the latter being contained in a porous tube.

According to Bunsen's experiments with equal surfaces, the powers of a platinum and carbon battery are nearly equal, and De la Rive says it is constant for a longer time. According to the experiments of MM. Liais and Fleury, the diaphragm of the Bunsen battery may be advantageously suppressed, and when the carbon is porous and impregnated with nitric acid, the conductibility of the pile is increased five-fold. To keep the carbon thus saturated with acid, it is surrounded by a glass cylinder, so as to keep an annular space between, which is filled with nitric acid. The two cylinders are fastened together at their lower ends with clay or cement; this form of the nitric acid battery is much used in Germany and France, but has not found much favour in this country.

(372) In the following series, the metals are arranged according to their electrical characters, and in the same relation to each other as zinc has to copper, so that any one of them operates as zinc to all those above it, and the more distant from one another any two metals stand in the series, the greater the galvanic action they will develop.

Platinum.	Mercury.	Tin.
Gold.	Copper.	Iron.
Silver.	Lead.	Zinc.

Hence, as we have already seen, a galvanic series of platinum and zinc is more powerful than one of copper and zinc; and the latter again more powerful than one of lead and zinc, &c. It is not, however, to be understood, that the power of any two metals in the table depends upon the *number* of intermediate ones, because a series of platinum and iron is much feebler than a series of copper and zinc; although in the former case there are six intermediate metals, and in the latter there are only three. Charcoal and plumbago stand higher in the scale of electric bodies than platinum, so that a galvanic series of plumbago and zinc is very powerful, as we have just seen. Now, plumbago or graphite is a combination of iron and carbon, and the hint was thrown out by Jacobi,* that by adding more carbon to that which usually enters into the composition of cast-iron, we should probably arrive at a compound whose galvanic properties would be equal to those of platinum. The object may be obtained by a species

* See his "Galvanoplastic Art," translated by Mr. Sturgeon, p. 4.

of cementation, or by re-melting cast-iron with additional carbon in closed vessels.

(373) This high *negative* character of carbon enables us to understand how it is that cast-iron and zinc form so effective a voltaic circle, standing as iron and zinc do immediately next each other in the above series. It was Mr. Sturgeon who first formed a large battery of these metals, (*Annals of Electricity*, vol. v.) It consisted of 10 cast-iron cylindrical vessels, and the same number of cylinders of amalgamated rolled zinc, with dilute sulphuric acid. The cast-iron vessels were 8 inches high and 3½ inches in diameter. The zinc cylinders were the same height as the iron ones, about 2 inches in diameter and open throughout. The iron and zinc cylinders were attached in pairs to each other by means of a stout copper wire. The zinc of one pair was placed in the iron of the next, and so on throughout the series; contact being prevented by discs of mill-board placed in the bottom parts of the iron vessels.

With ten pairs in series, Mr. Sturgeon states, that he usually obtained fourteen cubic inches of the mixed gases per minute, and ten and a half cubic inches, when the battery has been in action an hour and a half. On one occasion he states, that he obtained twenty-two cubic inches per minute, fused one inch of copper wire, one-twenty-fifth of an inch in diameter; kept four inches white hot, and eighteen inches red hot, in broad daylight. Eight inches of watch main-springs were kept red hot, and two inches white hot for several successive minutes.

(374) A prodigious battery, probably the largest ever made, in which cast iron was the negative element, was constructed by Dr. Callan (*Phil. Mag.* vol. xxxiii. 49). It consisted of 300 cast-iron water-tight cells, each containing a porous cell and zinc plate 4 inches square; 110 cast iron cells, each holding a porous cell and zinc plate 6 inches by 4; and 177 cast-iron cells, each containing a porous cell and a zinc plate 6 inches square. The entire battery consisted therefore of 577 voltaic circles, containing 96 square feet of zinc and about 200 square feet of cast-iron. It was charged by pouring into each cast-iron cell a mixture of twelve parts of concentrated nitric acid, and eleven and a half of double rectified sulphuric acid, and by filling to a proper height each porous cell with dilute nitro-sulphuric acid, consisting of about five parts of sulphuric acid, two of nitric, and forty-five of water. In charging the entire battery, there were used about fourteen gallons of nitric and sixteen of sulphuric acid.

(375) The first experiment made with this battery consisted in passing the current through a very large turkey, which was instantly killed, though it afterwards appeared that the whole discharge did

not take place through the body of the bird. In order to give the shock, a piece of tin-foil about four inches square was placed under each wing along the sides of the turkey, which were previously stripped of their feathers, and moistened with dilute acid. The foil was kept in close contact with the skin, by pressing the wings against the sides. The person who held the bird had a very thick cloth between each hand and the wing, in order to save him from the shock. When the discharge took place, the craw of the turkey was burst, and the hay and oats contained within it fell to the ground. When a copper wire in connexion with the negative end of the battery was put in contact with a brass ring, connected with the zinc end a brilliant light was instantly produced. The copper wire was gradually separated from the brass ring, until the arc of light was broken. The greatest length of the arc was about 5 inches. The length of the arc of light between charcoal points could not be determined, in consequence of the rapidity with which the charcoal burned away. At this period of the experiments several of the porous pots burst, and many of the copper slips became disconnected from the zinc cylinders, by the combustion of the solder; notwithstanding, however, this interruption of the circuit, the arc of light between the coke points was about an inch long, and the heat of the flame deflagrated a file.

(376) According to Dr. Callan's experiments a cast iron battery is about fifteen times as powerful as a Wollaston battery of the same size, and nearly as powerful and a half as Grove's, and hence the battery above described is equal in power to a Wollaston battery containing more than 1400 square feet of zinc, or more than 13,000 four-inch plates, and to a Grove's containing 140 square feet of platina. The largest copper and zinc battery ever constructed was that made by the order of Napoleon for the Polytechnic school, and which contained 600 square feet of zinc; and the most powerful Grove's, of which an account has been published, does not contain 20 feet of platina. Hence the above battery was more than twice as powerful as the largest Wollaston, and seven times as powerful as the largest Grove's ever constructed.

Callan has since (*Phil. Mag.* Feb. 1854) proposed as the negative element, sheet tin coated with an alloy of lead and tin, in which the proportion of tin is not greater than that of lead, or of lead, tin, and a small quantity of antimony. On tin plates thus coated, dilute sulphuric acid scarcely exerts any action. It may be platinized like sheet silver, or it may be coated with borax, and will then answer nearly as well as if platinized, these plates are far cheaper and more durable than platinized silver. Iron, coated with an alloy of lead and

tin, powerfully resists the action of oxidizing agents, especially if a little antimony be added.

(377) This surprising intensity of the zinc-iron circuit is thus explained by Professor Poggendorff (*Pog. Ann.* vol. i. 255).

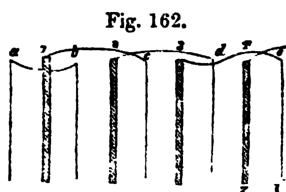
"The intensity of the voltaic circuit depends on two things,—electromotive force, and the resistance. It is the quotient from the division of the former by the latter. Now though the electromotive force between zinc and iron is smaller than between zinc and copper, silver, or platinum; nevertheless the current of the zinc-iron circuit is stronger, because the iron offers less resistance to the transition of the current than copper does. The current, however, possesses less tension than that of the copper circuit; or, in other words, it is weakened by the insertion of a foreign resistance in a greater proportion than that of the copper-zinc; and it was found that the interposition of a wire of German silver, fifty feet long, weakened the current from the iron-zinc more than that of the copper-zinc; and further it was supposed, that by a continued increase of the inserted resistance, it would be possible to make the current of the iron circuit, not only as weak, but even weaker than that of the copper circuit. Professor Poggendorff did not, however, succeed practically in effecting this.

(378) Mr. Roberts has, however, offered an explanation (*L. and E. Phil. Mag.* vol. xix. p. 196), which Electricians in this country will probably be inclined to adopt in preference to that given by the learned German, who is one of the most powerful and strenuous supporters of the Contact Theory of Galvanism. It is simply,—that copper, when immersed in an acidulated solution, does not retain so clean a metallic surface as iron does, when exposed to a like action. When a copper-zinc pair is placed in dilute sulphuric acid, an action takes place upon both the metals, and the balance of their affinities for the acid determines the direction of intensity of the electric current: but an obstacle to its free circulation arises by the resistance offered to its passage from the acid into the copper, because this metal has in a measure been acted upon by the acid, and its surface partially oxidated: but as the affinity of the base for the acid, under these circumstances, is not sufficient to cause the solution of the oxide, it therefore remains upon the surface of the copper-plate; and as oxides are worse conductors of Electricity than their metallic bases, we have here a resistance presented by the oxidated surface to the entrance of the electric current into the copper plate. On the other hand, when an iron-zinc pair is immersed in dilute acid, we have also an action on both metals; but the balance of affinities is here not so much in favour of the zinc, as when it is in combination with copper, and therefore the *intensity* or *electromotive force* gene-

rated by the iron-zinc, is not so great as in that of the copper-zinc battery: but the *quantity* circulated by the iron-zinc is greater, because the surface of the iron not only oxidates, as did the copper, but in consequence of its greater affinity for the acid, this oxide becomes dissolved in the liquid, and it is thus removed from the surface of the metal, which remains purely metallic, bright, and far more fitted to conduct Electricity than would be the oxidated surface of a copper plate: it therefore offers less resistance to its entrance, and a larger *quantity* is thus circulated, although (in consequence of the balance of affinities) in less intensity, or *electromotive force*, by an iron-zinc than by a copper-zinc galvanic pair.

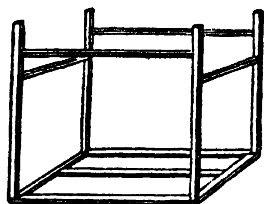
(379) Mr. Roberts has introduced a form of battery on the above principles, which, as it has been much used for blasting purposes, we shall here describe (*Proc. Elect. sec.* p. 357). For general purposes it consists of twenty single negative iron, and twenty single positive zinc plates, of six inches square, arranged alternately in a frame of wood, and connected in the following peculiar manner. Let the numbers and *z*, Fig. 162 represent the zinc, and the letters and *i*, the iron plates; let *a* and *b* be joined together, and stand free as a double terminal plate or pole, having of course a wire proceeding from them as a conductor; then join 1 to *c*, 2 to *d*, 3 to *e*, and so on, terminating the other end of the battery by a positive plate, but having both its surfaces opposed to a negative plate, as is the condition of 4.

Fig. 162.



In a battery of this construction there is no cross play of Electricity, because two plates intervene between every positive plate, and the negative plate in metallic connection with it. Its power is very great in consequence of the closeness of the plates one to the other. It is very compact, and the absence of insulating cells renders it very convenient, as it can with no trouble be put into, or taken out of, its box. The plates are put into a frame made of bars of wood, as in Fig. 163. The plates are kept from touching each other by strips or rods of wood about ¼ or ⅛ of an inch square, and long enough to extend from the top to the bottom of each plate, one rod to each side of a plate; or if the plate be very large, another in the middle. The box containing the exciting liquid (dilute sulphuric acid, one part acid to thirty of water) is put

Fig. 163.



together with white-lead joints, as these are perfectly water-tight. A battery of this construction is found to be far more powerful and constant in its action, than an equal sized one of copper and zinc.

(380) While speaking of the electrical properties of iron, we may take the opportunity to detail some peculiar voltaic conditions of that metal. In the *L. and E. Phil. Mag.*, vols. ix., x., and xi., several papers on this curious subject will be found, by Schoenbein, Faraday, and others; but we must confine ourselves here to the simple facts, referring to the original papers, for the theoretical explanations offered by the respective authors.

If one of the ends of an iron wire be made red hot, and, after cooling, be immersed in nitric acid, sp. gr. 1·35, neither the end that has been heated, nor any other part of the wire will be affected, whilst acid of this strength is well known to act rather violently upon common iron. By immersing an iron wire in nitric acid of sp. gr. 1·5, it becomes likewise indifferent to the same acid of 1·35.

(381) The principal facts that the writer has experimentally verified, and the observations which he has made, in repeating Schoenbein's experiments, are as follow :—

1°. It is well known, that when iron wire is immersed in nitric acid, sp. gr. 1·35, it is attacked with violence; but Sir John Herschel was, it seems, the first person who noticed that if the wire was associated with gold or platinum, it was quite inactive in acid of that strength. When an iron wire, one-sixteenth of an inch in diameter, was touched at a given point with platinum, and dipped into nitric acid, sp. gr. 1·37, it was not at all acted upon, but remained, for any length of time, perfectly bright. Once touching it in the acid with the platinum was sufficient to render it inactive when the platinum was removed, as long as it remained in the acid; but if it were taken out, wiped, and then again immersed, action commenced, but soon again ceased.

2°. If the acid was diluted with an equal bulk of water, platinum did not preserve iron wire from its action, even when coiled thickly round it: it appeared, indeed, rather to quicken the action; but although it did not protect the iron under these circumstances, it did under others which will be mentioned presently.

3°. If a wire, having been made inactive by being touched with a piece of platinum, was touched while in the acid with a piece of zinc, or another common iron wire, it was immediately thrown into violent action. Half of a wire, four inches long, was heated to dull redness, the blue tinge was visible through three inches: when the wire was cold, these three inches were quite inactive in nitric acid sp. gr. 1·39, the other end was active; but when the heated end was made bright by filing, it was rendered active likewise.

4°. When an inactive wire and one that was active, were dipped into the same vessel, and made to touch at their parts *above* the fluid, action was excited in the indifferent wire. A common wire was made to touch an indifferent one, and both dipped into nitric acid, the indifferent one going in *first*: by this means the common wire was rendered indifferent, not being in the slightest degree acted on by the acid; the second wire rendered indifferent a third; the third, a fourth; and so on. This experiment was found to succeed best with a wire that had been made indifferent by platinum; but with care, it will answer equally well with a wire that has been made indifferent in the fire, the conditions appearing to be, perfect contact and gradual immersion. When these wires were taken out of the acid, and wiped, they always returned to the active state, but were again made indifferent by repeating the process.

5°. A wire, polished very bright, and protected by platinum, was immersed in a solution of nitrate of copper in nitric acid, which acted very strongly on common iron, copper being deposited on the metal; the protected wire remained, however, bright; after a few seconds, the platinum was removed—the iron became instantly as common iron; but when the platinum was allowed to remain in contact an hour or two, and then removed, the wire was left in the peculiar state, exhibiting the curious phenomenon of a piece of polished iron remaining untarnished in a solution of acid nitrate of copper. The wire thus inactive, on being touched with a piece of common iron was instantaneously rendered active, undergoing rapid solution and becoming covered with a coating of copper.

6°. A piece of common wire was bent into the form of a fork, and slipped down an inactive wire into nitric acid, by which it was itself rendered inactive; now, if another piece of wire was made to touch the fork, before being introduced into the acid, it was rendered itself inactive; but if it was first thrown into action, and then made to touch either end of the fork, it threw all the wires into action, unless the first wire was one *rendered inactive by the fire*, in which case it was not thrown into action: the author could not, in this experiment, succeed in making one end of the fork active and the other passive, as described by Schoenbein; he tried it many times, and in every case every wire was thrown into action, when either was touched in the acid with an active wire.

7°. In order to observe the electrical phenomena, a galvanometer was used in the manner described by Faraday; a platinum wire was connected with one of the cups, and the other end dipped into a glass containing nitric acid, of the above strength; if now, an iron-wire was connected *first* with the other cup of the galvanometer, and then the other end immersed in the acid, it was inactive, and no deflection

of the needle took place; but if it was first put into the acid, and afterwards connected with the galvanometer, it was active, and the needle was deflected in the same manner as if it had been zinc, *i.e.*, whichever pole of the needle the wire of the galvanometer with which it was joined passed *immediately over*, moved *west*.

8°. If an inactive wire was in this experiment substituted for the platinum, it acted precisely as platinum, both with regard to its preserving action and to the direction of the electrical current produced; and here it may be observed that a striking proof is by this experiment afforded, that voltaic action is due to chemical action, for, when the wires were so arranged that both should be inactive, there was not the slightest electrical current evinced by the galvanometer; but when either was thrown into action by being touched by a common wire, that wire became instantly as zinc, and the needle was strongly deflected.

9°. If the iron-wire had a piece of platinum foil attached to it, the moment the circuit was closed, bubbles of gas made their appearance on the platinum, but none on the iron; but when the platinum was removed the gas rose rapidly from the iron, which was not, however, thrown into action.

10°. When two glasses were filled with acid, and connected by a compound platinum and iron-wire, all the phenomena which took place in a *single* glass were observed, and the platinum or inactive wire in one glass exerted a protecting influence on the iron on the other, provided the communication was first made through the galvanometer; a touch from a common wire also threw the iron into action, producing a strong electrical current; the same was the case with three or four glasses connected by a compound wire.

11°. When the acid was diluted, so as to have a sp. gr. of 1·2, platinum, as was before observed, could not protect iron from its action, neither when it was connected with the galvanometer did it, if the iron was dipped into the acid first; but if it was first connected with the galvanometer, and then put into the acid, *no action whatever took place in any length of time, even when the platinum was removed;* but it always commenced when the inactive wire was once touched in the acid with a common iron-wire, or with a piece of copper; but the iron thus made inactive did not as in strong acid possess the power of rendering other wire inactive, but was always thrown into action itself when a piece of common wire was substituted for the platinum, whether it was connected with the galvanometer first or not: the first wire in this case acted as platinum to the second.

12°. When two cups were employed, and connected by a piece of

bent wire, and so arranged that the iron-wire should be active, on removing the connecting wire, and taking a fresh piece, if it were dipped first into the cup containing the iron-wire, and then the other end brought into the platinum cup, *that end was inactive, and there was no passage for the electrical current, the needle of the galvanometer being quiescent; but when it was put into an active state the electrical current passed.* Here then we have the iron made inactive without any *metallic* communication with the platinum, and when inactive it is found incapable of conducting, or, at any rate, it obstructs very considerably the passage of an electrical current.

13°. If the iron-wire was inactive it was impossible to make either end of the connecting bent wire so, neither could it be, if it were dipped into the platinum cup *first*; the action of nitric acid of this strength, viz. 1·2, is not an effervescing action, the iron is slowly dissolved; when a piece of clean metal is dipped in it, it speedily becomes covered with a brown substance, which is gradually deposited, but dissolved by agitation.

14°. When iron-wire is made the positive electrode of a galvanic battery, consisting of fifteen or twenty pairs, and dilute nitric, sulphuric or phosphoric acid the subject of experiment, the negative electrode consisting of a platinum wire, if that pole be first dipped into strong nitric acid, and the circuit closed by a common iron-wire, that wire is immediately inactive, as regards the action of the acid on it, and it behaves precisely as platinum or gold in *giving off oxygen* from the decomposed water, while the platinum wire becomes surrounded with a greenish fluid (nitrous acid): any other mode of closing the circuit will not answer, and if, while oxygen is given off from the iron-wire, it is once brought into contact with the platinum, it ceases to give off oxygen when separated from it, and will not again do so till exposed to the air.

15°. The same phenomena occur with diluted acid, only hydrogen gas is given off in great abundance from the platinum, and as before, when the wires are made to touch in the liquid the iron ceases to perform the office of platinum, and becomes gradually dissolved; exposure to the air, however, brings it again to the peculiar state.

16°. Diluted sulphuric and phosphoric acid exhibit similar phenomena, but the iron cannot be made inactive in muriatic acid with that or any other voltaic power; it is always converted into muriate. When diluted nitric acid is employed, and when two cups are connected by a common iron-wire, the effects are the same; and if the connecting wire be removed, and the cups joined by another, in the manner before described, that end in the cup in which the platinum negative electrode was, gives off oxygen, while the other end under-

goes solution, and the iron-wire which acted the part of the positive electrode gives off oxygen also; if four cups be employed, a similar result is obtained; but the quantity of oxygen liberated diminishes as the number of elements increases: if either of the ends of the wires be now touched with a common iron-wire, its peculiar state is destroyed, and it becomes as the other end, while the oxygen it gave off appears to be divided between the two inactive wires; and if the iron-wire in immediate connection with the battery be made active, and all the others but the middle one made active, also, then the middle wire performs the office of the positive electrode.

Much more might be said on this curious subject; the above must, however, suffice here, and those who are anxious to see the matter fully discussed may be referred to the 9th, 10th, and 11th volumes of the *L. and E. Phil. Mag.* A voltaic battery, consisting of zinc and passive iron, or of active and passive iron, in either case excited after the manner of a Grove's battery, was described in a communication from Professor Schoenbein to the London Electrical Society. The power of the arrangement is said to be very great. Its economy is also a matter of importance, and the value of the salt produced (sulph. ferri) is not to be overlooked.

(382) The electrical character of an alloy of metals does not, it must be observed, always take a place between those metals of which it consists, but more frequently it stands either much higher or much lower in the series. Such is the case with brass, which mostly acts in galvanic arrangements, either quite as well, or even better than copper, which is one of its constituents. (Jacobi.) On the other hand, either amalgamated zinc, or a compound of zinc and quicksilver, acts even better than zinc alone, although quicksilver itself stands high in the galvanic series. A compound is described by Jacobi, which is still better than quicksilver and zinc; it consists of 38 parts of quicksilver, 22 parts of tin, and 12 parts of zinc. Nevertheless, he observes, in such alloys as these, where too much quicksilver is introduced, the disadvantage is, that they are extremely brittle, and have but little coherence.

(383) The inaction of amalgamated zinc in acidulated water is considered by Mr. Grove (*L. and E. Phil. Mag.*, vol. xv. p. 81) as being the effect of polarization; but of one which differs from ordinary cases of polarization, in that the *cations* of the electrolyte, instead of being precipitated on the negative metal, combine with it, and render it so completely positive, that the current is nullified, and not merely reduced in intensity as in other cases.

The experiments made by Mr. Grove, to verify this idea, are curious and striking.

1°. Half the surface of a strip of copper was amalgamated and immersed with a strip of zinc in water, acidulated with $\frac{1}{5}$th of sulphuric or phosphoric acid; on making the plates touch there was a rapid evolution of gas from the *unamalgamated* part of the copper, while only a few detached bubbles appeared on the amalgamated portion.

2°. A large globule of mercury was placed in the bottom of a glass of acidulated water, and by means of a copper wire, the whole surface of which was amalgamated, it was made to communicate with one extremity of a galvanometer, while a strip of amalgamated zinc, immersed in the same liquid, communicated with the other extremity; at the instant of communication an energetic current was indicated, which, however, immediately diminished in intensity, and at the end of a few minutes the needle returned to zero: scarcely any gas was evolved, and of the few bubbles which appeared, as much could be detected on the surface of the zinc as of the mercury.

3°. With the same arrangement a strip of platinum, well amalgamated, was substituted for the mercury. In a few minutes the current became null or very feeble, and if, after the cessation of the current, the zinc was changed for unamalgamated platinum, this latter evolved torrents of hydrogen, and the needle indicated a violent current in a contrary direction.

4°. With things arranged as in 2°, sulphate of copper was substituted for acidulated water,—a constant current was produced, and copper was precipitated on the mercury, as long as crystals of the sulphate were added to the solution.

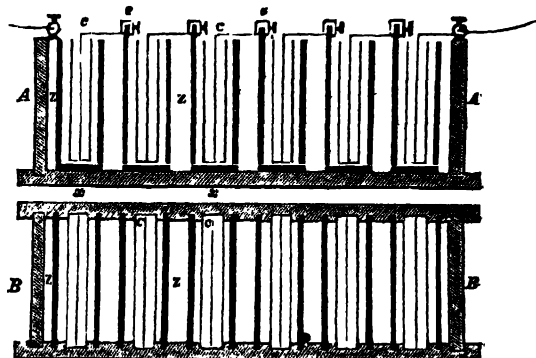
(384) In these experiments it is shown that mercury, which, in its normal state, is well known to be inefficient as the positive metal of a voltaic combination, is in many cases equally inefficient as a negative metal from its faculty of combining with the cations of electrolytes, which renders it equally positive with the metal with which it is voltaically associated, and the opposed forces neutralize each other. But if, as in 4°, the cation of the electrolyte is not of a highly electro-positive character, the zinc (or other associated metals) retains its superior oxidability, and the voltaic current is not arrested.

(385) The application of these experiments to the phenomena presented by amalgamated zinc, Mr. Grove thinks evident; all the heterogeneous metals with which the zinc may be adulterated, and which form minute negative elements, being amalgamated, become by polarization equally positive with the particles of zinc, and consequently without the presence of another metal to complete the circuit, all action is arrested as in the case of pure zinc. The fact of amalgamated zinc being positive with respect to common zinc, of

its precipitating copper from its solutions, and other anomalies, are also explained by these experiments.

(386) A form of voltaic battery, the arrangement of Dr. Leeson, in which, instead of sulphate of copper, a solution of bichromate of potash (ten parts water to one of bichromate), is employed as the exciting agent, is shown in Fig. 164. *A A* is a vertical, and *B B* a

Fig. 164.



horizontal section of the wooden trough rendered water-tight. It is grooved at the sides, as seen in *B B*, so as to receive the zinc plates Z Z: between each pair is a groove to receive the flat porous cell, containing the copper plate C. Each zinc plate rests on a piece of zinc, which forms as it were the bottom of a cell: one of each pair of zinc plates, Z, is higher than the other, as seen in the vertical section, for the convenience of forming the connection, which is effected by binding over the copper plate, and attaching it to the tall zinc one by a small binding screw, as seen at *e*. The trough is charged with acid solution, and the porous cell containing the copper with the solution of bichromate. Each trough contains ten or twelve cells. By having the zinc which surrounds the copper in three pieces, the trouble of binding is avoided, and it is much easier of manipulation. It will be seen by this, that the expensive plan of employing actual partitions between the respective pairs is avoided, each arrangement of zinc forming its own cell. It is scarcely requisite to mention, that the zinc is not of necessity to be accurately fitted in its groove, under the idea of making each cell water-tight, the fallacy of this idea having been long since developed.

(387) A beautiful little voltaic battery, and one of great power in which potassium is the positive element, is described by Mr. Goodman, (*Memoirs, Manchester Lit. and Phil. Soc.* vol. viii.) A wine glass was filled with dilute sulphuric acid, and in this was immersed

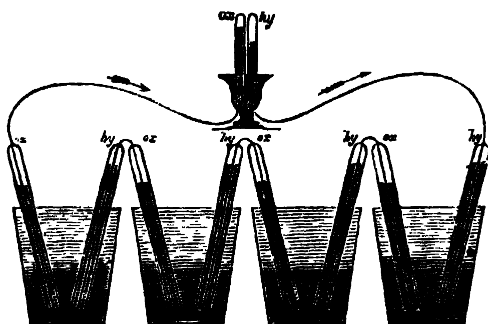
a plate of platinum just below the surface of the liquid. At the extremity of a short length of glass tubing a piece of membrane was tied, so as to close up its lower end, which was by an appropriate stand so fixed that the membrane or diaphragm should come in contact with the surface of the acidulated water immediately above the immersed plate of platinum. Into this tube was dropped a globule of mercury, which lying upon the membrane would serve to amalgamate and keep in that condition the piece of potassium destined for that situation. The tube was then filled with mineral naphtha, so that the metal could be raised with pleasure into a medium in which it would remain perfectly quiescent, and would only suffer loss when required to do so. The potassium, weighing about half a grain, was now screwed upon the "topped" extremity of a copper wire, upon which a shoulder or button of wood was also screwed, about one-sixteenth of an inch from its extremity, to prevent the wire perforating the potassium too far, and coming itself in contact with the diaphragm. This wire was in metallic communication with the immersed platinum, and for the purpose of raising or depressing the potassium in its cell, a moveable mercury cup formed the medium of communication. From this the potassium hung suspended by its wire, upon which a small weight was affixed to insure the continuous contact and close application of this metal to the membrane. With the apparatus thus arranged, it was found that potassium became a very *manageable element* in a voltaic battery, and on lowering it into contact with the diaphragm a continuous current of 45° to 50° was observed by the aid of an intervening galvanometer. Acidulated distilled water was energetically decomposed by this miniature galvanic battery, and Mr. Goodman even succeeded in producing a sensible and measurable deflection gold leaf with a single cell.

(388) A most extraordinary and perfectly novel voltaic battery, in which the active ingredients are gases, was described by Mr. Grove (*Phil. Mag.* Dec. 1842; *Phil. Trans.* part ii., 1843; and part ii. 1845). It consisted originally of a series of 50 pairs of platinized platinum plates, each about a quarter of an inch wide, enclosed in tubes partially filled alternately with oxygen and hydrogen gases, as shown in Fig. 165. The tubes were charged with dilute sulphuric acid, sp. gr. 1·2, and the following effects were produced:

1st. A shock was given which could be felt by five persons joining hands, and which when taken by a single person was painful.

2nd. The needle of a galvanometer was whirled round, and stood at about 60°; with one person interposed in the circuit it stood at 40°, and was slightly deflected when two were interposed.

Fig. 165.



3rd. A brilliant spark visible in broad daylight was given between charcoal points.

4th. Iodide of potassium, hydrochloric acid, and water acidulated with sulphuric acid, were severally decomposed: the gas from the decomposed water was eliminated in sufficient quantity to be collected and detonated. The gases were evolved in the direction denoted in the figure, i. e., as the chemical theory and experience would indicate, the hydrogen travelling in one direction throughout the circuit, and the oxygen in the reverse. It was found that twenty-six pairs were the smallest number which would decompose water, but that four pairs would decompose iodide of potassium.

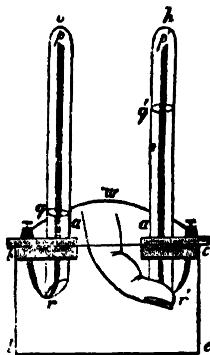
5th. A gold leaf electroscope was notably affected.

When the tubes were charged with atmospheric air, no effect was produced, nor was any current determined when the gases employed were carbonic acid and nitrogen, or oxygen and nitrogen: when hydrogen and nitrogen gases were used, a slight effect was observed, which Mr. Grove is inclined to refer to the *oxygen* absorbed by the liquid when exposed to the air, which, with the hydrogen, would give rise to a current.

The voltaic current generated by this battery is attributed by Mr. Grove to chemical synthesis, of an equal but opposite kind, in the alternate tubes, at the points where the liquid, gas, and platinum meet, and the object of covering the platinum with the pulverulent deposit was to increase the number of these points, the liquid being retained upon the surface of the platinum by capillary attraction. Schoenbein considers (*Phil. Mag.*, March, 1843) that the oxygen does not immediately contribute to the production of the current, but that it is produced by the combination of hydrogen with water, a suboxide of hydrogen being formed. In consequence of this opinion, Mr. Grove undertook a searching investigation into the phenomena, and the following are some of his principal results.

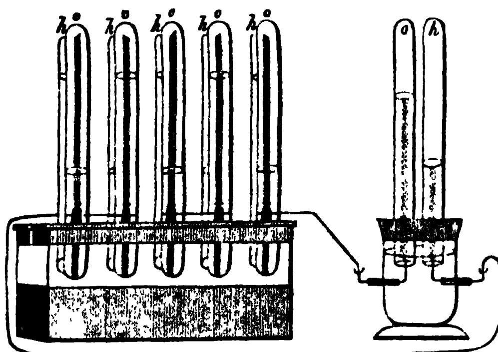
(389) In order conveniently to examine the gases either after or during an experiment, without changing the liquid in which the tubes are immersed, the form of cell shown in Fig. 166 was adopted.

Fig. 166. Fig. 167.



b c d e is a parallelopiped glass or stoneware vessel, such as is commonly used for the outer cells of the nitric acid batteries. The tubes are cemented into pieces of wood *a b*, *a c*, and can, with the wood, be separately detached from the trough, as shown in Fig. 167. At the aperture or space *a a*, between the tubes, there is just room for a finger to enter, close the orifice of either tube, and thus detach it from the apparatus. The platinum foil is turned up round the edge of the tube, and brought into connection with a binding-screw screwed into the wood. In Fig. 168 a battery and five cells of this

Fig. 168.



construction, each containing about $1\frac{1}{3}$ cubic inch, is represented as charged with oxygen and hydrogen, connected with a decomposition of water apparatus. With a battery of 50 of these cells there was but a trifling difference in the rise of the liquid in all the cells, and the rise of gas in the decomposing apparatus was so directly proportional that an observer unacquainted with the rationale of the voltaic battery would have said the gases from the exterior cells were conveyed through the solid wires, and evolved in the voltameter.

(390) In order to decide the question whether the points of action were, where the liquid, gas, and platinum met, or whether the gases entered into solution first, and were then electro-synthetically combined by the immersed portion of the platinum, a series of ten cells was constructed in which the platinum reached only to half the

height of the tubes. This was charged with oxygen and hydrogen, so that the liquid just covered the extremities of the platinum. Here, it is evident that the gases must enter into solution before the platinum could affect them, and the result was that a highly sensitive galvanometer was but slightly affected, but when a little gas was added so as to expose the platinum to a gaseous atmosphere, a considerable current was developed, proving that it is at the exposed portion of the platinum plate that the real work of the battery is carried on.

(391) The analogy of the hydrogen tube to the zinc plate of an ordinary voltaic battery was beautifully shown by arranging a single pair with oxygen and hydrogen, and a second pair with hydrogen in one tube, and dilute sulphuric acid in the other; the oxygen of the first was metallically connected with the hydrogen of the second, and the hydrogen of the first with the liquid of the second hydrogen gas immediately rose from the platinum. In short, though it required four pairs to decompose water with *immersed* platinum electrodes, yet the platinum in the atmosphere of hydrogen being analogous to an oxidable anode, one pair was with this assistance sufficient to decompose water. The analogy of the gaseous and metallic voltaic batteries was further shown by charging three cells alternately with hydrogen and *nitric acid;* water was decomposed, the gaseous hydrogen deoxidizing the nitric acid in this arrangement, just as nascent hydrogen does in the metallic battery. A battery of two cells charged with hydrogen and dilute sulphuric acid was powerless in an atmosphere of pure nitrogen, a fact conclusive against the view which regards hydrogen and water as the efficient agents in the gas battery.

(392) Mr. Grove describes a series of experiments with other gases: the following is a general account of his results with ten cells charged in series.

Oxygen and protoxide of nitrogen	No effect on iodide of potassium.
Oxygen and deutoxide of ditto .	Very slight, soon ceasing.
Oxygen and olefiant gas . .	Very feeble, but continuous.
Oxygen and carbonic oxide . .	Notable effects. Slight symptoms of decomposing water.
Oxygen and chlorine . . .	Considerable action at first, scarcely perceptible in 24 hours.
Chlorine and dilute sulphuric acid	About the same.
Chlorine and hydrogen . .	Powerful effects. Two cells decomposing water.
Chlorine and carbonic oxide. .	Good. Ten cells decomposing water.
Chlorine and olefiant gas . .	Feeble.

The most interesting practical result of Mr. Grove's experiments on the gas battery will probably be its application to eudiometric purposes. "Two narrow cubic inch tubes of seven inches long were carefully graduated into 100 parts. These were immersed in separate vessels of dilute sulphuric acid, and filled with atmospheric air exactly to the extreme graduation; the water-mark within the tube was examined when exactly at the same level as the exterior surface of the liquid: folds of paper were used to protect them from the warmth of the hands and thus prevent expansion; the barometer and thermometer were examined, and every precaution taken for accurate admeasurement. One of these tubes was left empty, in order to ascertain and eliminate from the result the effect of solubility. Into the other was placed a slip of platinized platinum foil, one quarter of an inch wide. This strip of foil was connected by a platinum wire with another strip placed in a tube of hydrogen and inserted in the same vessel. After the circuit had been closed for two days, the liquid was found to have risen in the graduated tube 22 parts out of the 100; in the tube placed by its side, it had risen one division. The tubes were allowed to remain several days longer, but no further alteration took place. This analysis gives therefore 21 parts in 100 as the amount of oxygen in a given portion of air." In these experiments, it must be observed that only a single pair of the gas battery can be used, as, if more be employed, the electrolyte is likely to be decomposed, and gas added to the compound.

Another useful application of this interesting battery is the means which it affords of obtaining perfectly pure *nitrogen*. All the oxygen in a given quantity of air may be abstracted, as well as the free oxygen contained in the liquid which confines it, and by subsequently introducing into the tube a little lime water, the trifling quantity of carbonic acid may be removed.

With respect to the theory of the gas battery, Mr. Grove says: "Applying the theory of Grotthus to the gas battery, we may suppose that when the circuit is completed at each point of contact of oxygen, water and platinum in the oxygen tube, a molecule of hydrogen leaves its associated molecule of oxygen to unite with one of the free gas; the oxygen thus thrown off unites with the hydrogen of the adjoining molecule of water, and so on, until the last molecule of oxygen unites with a molecule of the free hydrogen: or we may conversely assume that the action commences in the hydrogen tube." .... "There are one or two other theoretical points as to which the gas battery offers ground of interesting speculation; the contact theory is one. If my notion of that theory be correct, I am at a loss

to know how the action of this battery will be found consistent with it, if indeed the contact theory assumes contact as the efficient cause of voltaic action; but admit that this can only be circulated by chemical action, I see little difference, save in the mere hypothetical expression, between the contact and chemical theories; any conclusion which would flow from the one, would likewise be deducible from the other. There is no observed sequence of time in the phenomena, the contact, or completion of the circuit, and the electrolytical action are synchronous. If this be the view of contact theorists, the rival theories are mere disputes about terms; if, however. the contact theory connects with the term contact an idea of force which does or may produce a voltaic current, independently of chemical action, a force without consumption, I cannot but regard it as inconsistent with the whole tenor of voltaic facts and general experience."

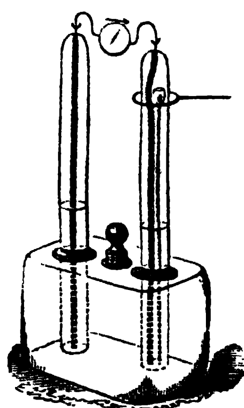
In a postscript appended to this paper, Mr. Grove details some further experiments, the theory of which seems at present by no means clear. On repeating the eudiometrical experiment already described, with an apparatus in which the external air was shut out, it was found, after the expiration of three days, that the volume of gas in the air-tube which had previously contracted had now *increased* and continued to do so. Mr. Grove at first believed that *nitrogen was decomposed;* he subsequently, however, found that the increase was due to the addition of *hydrogen,* and that in order to obtain the effect with certainty two points were essential; first the exclusion of any notable quantity of atmospheric air from solution; and secondly, great purity in the hydrogen; it hence becomes necessary in order to ensure accuracy in eudiometric experiments, either purposely to use common hydrogen, or to employ closed vessels the tubes of which are long and narrow; and having first charged the tubes with hydrogen and atmospheric air, to allow these to remain in closed circuit until all the oxygen is abstracted, and a little hydrogen added by the electrolytic effect to the residual nitrogen; then to substitute oxygen for the original hydrogen, which will in its turn abstract hydrogen from the nitrogen, and leave only *pure* nitrogen. This, Mr. Grove says, he has frequently done with perfect success.

The only way at present of accounting for the fact disclosed in these last experiments, appears to be, to regard mixed gases as in a state of feeble chemical union, the effect being produced by the affinity of the nitrogen or carbonic acid for the hydrogen; the affinity of the oxygen of the water being balanced between the

hydrogen in the liquid and that in the tube, would enable the resultant feeble affinity of the nitrogen for hydrogen to prevail. Mr. Grove does not, however, venture a positive opinion; the fact, as he says, "that gaseous hydrogen should abstract *oxygen from hydrogen* without the latter forming any combination, being so novel, that attempted explanation is likely to prove premature."

(393) The form of gas battery employed by Mr. Grove in his later experiments, and which possesses the great advantage of entirely preventing the interfering action of the atmosphere, is shown in Fig. 169. In this battery, oxygen and deutoxide of nitrogen gave a continuous current, and a permanent deflection of the galvanometer was produced, when a piece of phosphorus was suspended in the nitrogen tube, the product being phosphorous acid; and the curious instance was exhibited of the employment of a solid, insoluble non-conductor, and the existence of a continuous voltaic current, and of a true combustion; the combustible and the "comburant" being at a distance: phosphorus burned by oxygen which is separated from it by strata, both of water and gas, of indefinite length. A current was likewise produced by *sulphur* in nitrogen and oxygen, the sulphur being contained in a little capsule of glass that could be heated by a small hoop of iron with a handle as shown in the figure, the moment the sulphur entered into fusion, the needle of the galvanometer moved, and it continued deflected during the whole time it remained in the fused state. Various other substances, such as camphor, oil of turpentine, oil of cassia, alcohol, ether, &c., were thus tried, and all produced notable voltaic effects, and a field has thus been laid open for ascertaining the voltaic relations and quantitative electro-chemical combinations of solid and liquid substances, which from their physical characteristics have not hitherto been recognized in lists of the voltaic relations of different substances, and consequently formed to a certain extent a blank in the chemical theory of the voltaic pile.

Fig. 169.



(394) *Ohm's law.*—In none of the various forms of the hydro-electric battery do we obtain in the form of a current the whole of the Electricity excited by the chemical action on the positive element. The amount of Electricity realized, or, in other words, the *force* of the current, is equal to the sum of the electromotive forces,

divided by the sum of the resistances in the circuit; thus, let F denote the actual force of the current, E the electromotive force, and R the resistance:

$$F = \frac{E}{R}$$

By the term electromotive force, is to be understood the cause which in a closed circuit originates an electric current, or in an unclosed one gives rise to an electroscopic tension. According to the chemical theory, it is the affinity between the active metal and the element of the liquid compound on which it acts. By the term resistance is signified the obstacle opposed to the passage of the electric current by the bodies through which it has to pass; it is the inverse of what is usually called their conducting power.

(395) The different causes which influence the quantity of Electricity obtained in a voltaic circuit have been investigated mathematically by Professor Ohm, of Nuremberg; a translation of whose paper is to be found in Taylor's Scientific Memoirs, vol. ii., and his formulæ, which have been verified by the researches of Daniell and Wheatstone, may be regarded as the basis on which all investigations that have since been made relative to the force of the voltaic current have been founded.

(396) By increasing the number of elements of a voltaic series we increase the tension, urging the Electricity forward, but then at the same time we increase the amount of resistance offered by the liquid portion of the circuit; so that, provided in both cases the circuit be completed by a *perfect* conductor as a stout copper wire, we obtain precisely the same results in both cases, the electromotive forces and the resistances being increased by an equal amount, for,

$$\frac{E}{R} = \frac{n\,E}{n\,R}$$

But it is very different when the circuit is closed by an *imperfect* conductor: for a resistance which might weaken to a considerable extent $\frac{E}{R}$ might not sensibly diminish $\frac{n\,E}{n\,R}$, and in accordance with this we find that when great resistances have to be overcome, it is necessary to increase the number of elements in proportion to those resistances.

(397) The resistances to the circulation of available Electricity are of a two-fold character. We have first R, the resistance in the battery cell, which varies directly with the distance between the plates and inversely as the area of the efficient section of the liquid, and which Daniell has shown to be the mean of that of the opposed faces of the metals; and we have *r*, the specific resistance of the

conducting wire. The amount of work which a battery is capable of performing may be expressed therefore by the fraction,

$$F = \frac{E}{R + r}$$

In a single circle closed by a good conductor, the value of r nearly vanishes, and the force of the current is proportional to the superficies of the metallic elements. In a compound circle, the following general formula expresses the force of the current when the circuit is completed by a connecting wire:

$$F = \frac{n\,E}{\frac{n\,R\,D}{S} + \frac{r\,l}{S}}$$

where the other letters signifying the same as before.

D = The distance between the plates.
S = The section of the plates in contact with this liquid.
l = The length of the conducting wire.
S = The section of the same.
n = The number of element.

This formula leads to the following general law. (Wheatstone, *Phil. Trans.* 1843.)

1°. "The electromotive force of a voltaic circuit varies with the number of the elements, and the nature of the metals and liquids which constitute each element, but is in no degree dependent on the dimensions of any of their parts.

2°. "The resistance of each element is directly proportional to the distances of the plates from each other in the liquid, and to the specific resistance of the liquid; and is also inversely proportional to the surface of the plates in contact with the liquids.

3°. "*The resistance of the* connecting wire of the circuit is directly proportional to its length, and to its specific resistance, and inversely proportional to its action."

(398) The method employed by the German electricians for measuring the strength of the hydro-electric current, was by observing its effect on the magnetic needle, the force of the current being estimated from the angle of deviation. When the galvanometer consists merely of a single stout copper wire placed immediately under, and parallel to, a common variation needle, the force of the current acting on the needle was determined by Kämtz to be *proportional to the product of the sine into the tangent of the angle of declination;* and to save the trouble of making a calculation for each experiment, the following table (Peschel's *Elements of Physics*) was drawn up by Pohl, from which the proportional force

of any current may be ascertained for any declination given in degrees from 1° to 90°.

Deflection of Needle.	Intensity of Current.	Deflection of Needle.	Intensity of Current.	Deflection of Needle.	Intensity of Current.
1°	0·0001	31°	0·1016	61°	0·5179
2	0·0004	32	0·1087	62	0·5451
3	0·0009	33	0·1161	63	0·5740
4	0·0016	34	0·1238	64	0·6049
5	0·0025	35	0·1328	65	0·6380
6	0·0036	36	0·1402	66	0·6735
7	0·0049	37	0·1489	67	0·7119
8	0·0064	38	0·1579	68	0·7533
9	0·0081	39	0·1673	69	0·7983
10	0·0100	40	0·1770	70	0·8475
11	0·0122	41	0·1872	71	0·9014
12	0·0145	42	0·1978	72	0·9608
13	0·0170	43	0·2088	73	1·0268
14	0·0198	44	0·2202	74	1·1004
15	0·0228	45	0·2321	75	1·1833
16	0·0259	46	0·2445	76	1·2775
17	0·0293	47	0·2574	77	1·3854
18	0·0330	48	0·2709	78	1·5106
19	0·0368	49	0·2850	79	1·6577
20	0·0409	50	0·2997	80	1·8334
21	0·0452	51	0·3150	81	2·0471
22	0·0497	52	0·3313	82	2·3133
23	0·0544	53	0·3479	83	2·6536
24	0·0594	54	0·3653	84	3·1061
25	0·0647	55	0·3840	85	3·7378
26	0·0702	56	0·4035	86	4·6830
27	0·0759	57	0·4239	87	6·2551
28	0·0819	58	0·4455	88	9·6133
29	0·0882	59	0·4683	89	18·8034
30	0·0948	60	0·4924	90	infinite.

(399) Ohm determined the intensity of a current by the multiplier, but instead of measuring the declination of the needle, he observed the amount of torsion of the fine wire by which the needle was suspended, the intensity of the current being proportional to the number of degrees which the torsion index was moved back. Fechner determined the number of oscillations made by the needle of a galvanometer placed in the magnetic meridian under the influence of the current, the conducting wire intersecting the magnetic meridian at right angles. "The intensities of the currents are *inversely* as the squares of the times of the vibrations; or the number of units of time which are required to complete the same number of vibrations." Thus, supposing that the number of vibrations made by the needle under the influence of a current a in 10 seconds is made under the influence of another current b in 5 seconds, then $a : b = \frac{1}{10^2} : \frac{1}{5^2} = \frac{1}{100} : \frac{1}{25} = 25 : 100 = 1 : 4$.

Therefore the intensity of the current *b* is four times greater than that of the current *a*. Pohl, by following the same method of magnetic measurements, arrived at the following law, which was practically verified by Peschel, viz.: "That the intensities of currents of single hydro-electric batteries, in which both electromotors present equal surfaces to the exciting fluid, are, *cæteris paribus*, as the *biquadrate roots* of the areas of the surfaces in action;" from which it follows that to construct a battery, the intensity of whose current shall be double that of another given battery, the exciting surface of the former must be 16 times greater than that of the latter.

(400) In their verifications of Ohm's theory, the German and French electricians adopted Fechner's method. They first observed the oscillations of the needle where no extraneous resistance was introduced into the circuit, and they then added a known resistance, and again measured the oscillations. Wheatstone adopted a different method; instead of *constant*, he employed *variable* resistances, bringing thereby the currents in the circuits compared to equality, and inferring, from the amount of the resistance measured out between two deviations of the needle, the electro-motive forces and resistances of the circuit according to the particular conditions of the experiment. For this purpose he invented an instrument which he calls a *rheostat;* it consists essentially of two cylinders, one of wood, on which a spiral groove is cut, and round which is coiled a long wire of very small diameter, and the other of brass; by means of a handle any part of the wire can be unwound from the wooden cylinder and wound on to the brass. The coils on the wood cylinder being insulated and kept separate from each other by the groove, the current passes through the entire length of the wire coiled upon that cylinder, but the coils on the brass cylinder not being insulated, the current passes immediately from the point of the wire, which is in contact with the cylinder, to a spring in metallic communication with the wires of the circuit. The effective part of the length of the wire is therefore the variable portion which is on the wooden cylinder. The cylinders are six inches in length and $1\frac{1}{2}$ inch in diameter; the threads of the screw are 40 to the inch, and the wire is of brass $\frac{1}{100}$th of an inch in diameter. Very thin and badly conducting metal is employed in order to introduce a greater resistance into the circuit; a scale is placed to measure the number of coils unwound, and the fractions of a coil are determined by an index which is fixed to the axis of one of the cylinders and points to the divisions of a graduated scale.

(401) For measuring very great resistances, as long telegraph

wires, or imperfectly conducting liquids, Wheatstone employs a series of coils of fine silk covered copper wire about the $\frac{1}{100}$ of an inch in diameter; two of these coils are 50 feet in length, the others are respectively 100, 200, 400, and 800 feet in length. The two ends of each coil are attached to short thick wires, fixed to the upper faces of the cylinders, which serve to combine all the coils in one continuous length. On the upper face of each cylinder is a double brass spring, moveable round a centre, so that its ends may rest at pleasure either on the ends of the thick wires united to the circuit, or may be removed from them and rest on the wood. In the latter position, the current of the circuit must pass through the coil, but in the former position the current passes through the spring, and removes the entire resistance of the coil from the circuit. When all the springs rest on the wires, the resistance of the whole series of coils is removed; but by turning the springs so as to introduce different coils into the circuit any multiple of 50 feet up to 1600 may be brought into it. Wheatstone finds that the resistance of the entire 1600 feet is equivalent to 218·880 units of resistance, or feet of the standard wire (diameter ·071 of an inch). He also sometimes employs six other coils, each containing 500 yards of wire. The reduced length of this series is above 233 miles of the standard wire, and by combining this series of coils with the preceding, he is able to measure resistances equal to 274½ miles. For measuring comparatively small resistances, Wheatstone employs a cylinder 10½ inches in length, and 3¼ in diameter, round which is wound 108 coils of a copper wire $\frac{1}{40}$th of an inch thick, any part of which can, by turning the cylinder, be included in the circuit; but the thickness, length, and material of the wire may be varied according to the limits of the variable resistance required to be introduced into the circuit, and the degree of accuracy with which these changes are required to be measured. This form of *rheostat* may be usefully employed as a regulator of a voltaic current in order to maintain for any required length of time precisely the same degree of force, or to change it in any required proportion. It would serve as a regulator for an electro-magnetic engine. In Volta-typing operations the advantage of using the rheostat is obvious, by varying it from time to time so as to keep the needle of the galvanometer (which should consist of a single thick plate or wire, making a single convolution) to the same point, a current of any required degree of energy may be maintained without any notable increase or diminution, for any length of time. These two forms of the rheostat are shown in Figs. 170, 171; Fig. 170 being the instrument employed for great resistances, and Fig. 171 that used when the resistances are smaller.

Fig. 170.

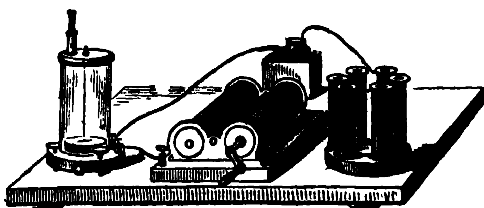
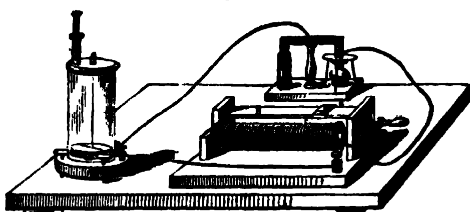


Fig. 171.



(402) By means of his *rheostat*, Wheatstone has shown that the number of turns of the cylinder requisite to reduce the needle of the galvanometer from one given degree to another, is an accurate measure of the electromotive force of the circuit. He has also proved that similar voltaic elements of various magnitudes conformably to theory, have the same electromotive force; that the electromotive force increases exactly in the same proportion as the number of similar elements arranged in series; and that when an apparatus for decomposing water is placed in the circuit, an electromotive force opposed to that of the battery is called into action, which is constant in its amount, whatever may be the amount of the number of elements of which the battery consists. The electromotive forces of Voltaic elements formed of an amalgam of potassium with zinc, copper, and platinum, a solution of a salt of the electro-negative metal being the interposed liquid, are given: the last combination is one of great electromotive energy, and when a voltameter is interposed in the circuit, it decomposes water abundantly. A still more energetic electromotive force is exhibited by a voltaic element, consisting of amalgam of potassium, sulphuric acid, and a plate of platinum covered with a film of peroxide of lead. A series of 10 such elements being equal to 33 of Daniell's, or 50 of Wollaston's cells.

CHAPTER VIII.

EFFECTS OF THE VOLTAIC CURRENT.

Luminous, thermal, magnetic, and physiological phenomena.

(403) On comparing the Electricity of the Voltaic battery with that of the Electrical battery, we find a difference between the two which may be expressed in the three following particulars:—1°. The *intensity* of voltaic Electricity, as compared with statical, is exceedingly *low:* 2°. The quantity of Electricity set in motion by the smallest voltaic circle is almost infinitely greater than that from the electrical machine; indeed, it has been shown by Faraday (*Exp. Resear.*, 371, *et seq.*) that two wires—one of platinum and one of zinc, each one-eighteenth of an inch in diameter—placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acid, consisting of one drop of oil of vitriol and four ounces of distilled water, at a temperature of about 60°, and connected at the other extremities by a copper wire, eighteen feet long and one-eighteenth of an inch thick, yield as much Electricity in eight beats of a watch, or $\frac{8}{150}$ of a minute, as an electrical battery, consisting of fifteen jars, each containing 184 square inches of glass, coated on both sides, and charged by thirty turns of a fifty-inch plate machine: 3°. While the discharge of the *electrical* battery is instantaneous; in the *voltaic* battery a current circulates in an uninterrupted and continuous stream, although the wire uniting the opposite ends is constantly tending to restore the electric equilibrium.

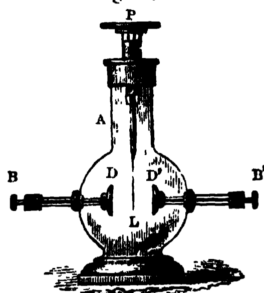
(404) In considering the effects of voltaic Electricity, it will be convenient to do so in relation to these three circumstances, as contrasting it with ordinary Electricity. In a former chapter it has been shown, that a piece of glass or sealing wax rubbed with flannel, and held near the cap of the gold-leaf electroscope, causes an immediate divergence of the leaves; but the largest calorimotor that has ever been constructed is incapable of producing an equal effect: indeed, it is only by the application of the condenser that any indi-

cations of Electricity can be obtained from it;* but with a battery of many pairs the effect is very distinct, though water be the sole exciting agent, as we have already seen (340). And it matters not what the size of the plates may be; pairs of copper and zinc, one quarter of an inch square, being quite as effectual as plates four inches square, numerous alternations being the only requisite. Here then we see a remarkable difference between the simple and the compound voltaic circle, and between quantity and intensity. From the largest calorimotor that was ever constructed, we can obtain no direct shock, and only feeble electro-chemical effects, while thirty or forty pairs of zinc and copper, four inches square, excited by the same acid, will diverge gold leaves, give shocks, and decompose acidulated water very rapidly: in general terms it may be stated, *cœteris paribus*, that the *quantity* of the electric current bears a relation to the size of the plates, and the *intensity* to the number of the alternations.

(405) *Thermal and luminous phenomena.*—The wonderful heating powers of an extensive voltaic battery, and the intense light emitted between charcoal points, were noticed in the last chapter (363). In the Proceedings of the Electrical Society (4to. volume), a series of experiments performed with a sulphate of copper battery, consisting of 160 cells, are detailed. The deflagration of mercury is described as most brilliant; and the length of the flame between charcoal points, was three-fourths of an inch. Zinc turnings were speedily deflagrated, and their oxide was seen floating about the room. In these experiments, the following interesting result was *first* obtained:

* With the aid of the electroscope shown in Fig. 172, constructed by Mr. Gassiot, the Rev. Charles Pritchard (*Phil. Trans.* 1844) obtained signs of tension in a single cell excited by dilute sulphuric acid with platinum and zinc. A is a glass vessel, the stem of which is well coated with lac; B B' two copper wires passing through glass tubes and corks; D D' gilt discs, each about two inches in diameter, attached to the wires; P a copper plate, with a wire passing through a glass tube; to the end of the wire is attached a narrow slip of gold leaf L. The discs must be adjusted with care, so as to allow the leaf to be equidistant from each. If B is connected by a wire attached to the platinum, and B' to another wire attached to the zinc of a single cell of the nitric acid battery insulated on a plate of lac, and an excited glass rod is approximated very gradually towards the plate P, the gold leaf will be attracted to B', or the disc attached to the zinc; and if excited resin is approximated in a similar manner, the gold is then attracted to B or the disc attached to the platinum.

Fig. 172.

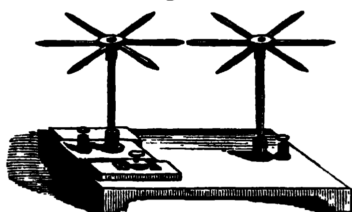


When the ends of the main wires were placed across each other (at about one or two inches from their extremities, not touching, but with an intervening stratum of air, the striking distance through which the Electricity passed, producing a brilliant light), that wire connected with the *positive* end of the battery became red-hot from the point of crossing to its extremity. The corresponding portion of the other wire remained comparatively cold. The wires were removed from the battery: that which had been made the positive was made the negative, and that which had been *negative* was made positive. The results were still the same:—the *positive* wire becoming in all cases heated from its end to the point of crossing, and finally bending beneath its own weight. When a piece of sulphuret of barium was placed on the table, with one wire resting on it, upon bringing the other to within the striking distance, the portion contiguous to the wire was fused, but could not be collected. When sulphuret of lead was similarly placed, the metal was released in small quantities, but when sulphuret of antimony was placed in circuit the most brilliant effects were obtained. The negative wire was firmly held on the sulphuret, and the positive brought to within one-eighth of an inch of it, the heat of the flame immediately disengaged the elements combined with the metal, and they were dissipated in the form of vapour, leaving a small portion of fused metal in a state of intense heat. When the main wires were crossed, and their ends placed in two similar jars, containing distilled water, in about two minutes the water in the positive cell boiled; that in the other presenting no such appearance. On applying a powerful magnet the flame from the charcoal points obeyed the known laws of electro-magnetism, being attracted or repelled as the case might be, or following the motion of the magnet if the latter was revolved. But when a powerful horse-shoe magnet was held horizontally with its *north* or marked end uppermost, and the wire from the negative side of the battery firmly pressed on the magnet, the positive wire being brought to within the striking distance, a brilliant circular flame of electrical light was *seen to revolve from left to right as the hands of a watch*. When the position of the magnet was reversed, the flame revolved from *right to left*. The appearance of the flame was not unlike that of the brush from the electrical machine received on a large surface, only much more brilliant.

(406) The colour of the light which attends the voltaic disruptive discharge varies with the substances between which the discharge passes. If thin metallic leaves be employed, they are deflagrated with considerable brilliancy. The beautiful effects are not, however, owing to the combustion of the metals, though in some cases in-

creased by this cause, but arise from a dispersion of their particles analogous to that of the more momentary explosion of the Leyden battery. Gold leaf emits a white light, tinged with blue; silver, a beautiful emerald green light; copper, a bluish white light, with red sparks; lead, a purple; and zinc, a brilliant white light, tinged with red. The experiments may be performed by fixing a plate of polished tinned iron to one wire of the battery, and taking up a leaf of any metal on the point of the other wire, bringing it in contact with the tin plate. Even under distilled water the disruptive discharge of the voltaic battery takes place in a stream of brilliant light.

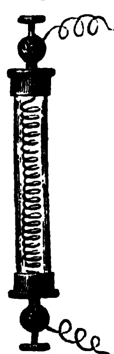
Fig. 173.



Mr. De la Rue has contrived the arrangement, shown in Fig. 173, for submitting metals to the action of the voltaic current. It consists of two brass columns surmounted by a series of holders which move on centres, and any two opposed points are brought into contact by a rack and pinion adjustment.

(407) The best method of showing the power of the voltaic current to heat metallic wire, is to roll about eighteen inches of wire into a long spiral, and to place it in the interior of a glass tube, Fig. 174, its ends passing through corks, or attached to screws, so as to be readily connected with the terminal wires of the battery: by this means a high temperature may be communicated to the glass tube, though the wire may not be ignited; and by immersing it in a small quantity of water, that fluid may speedily be raised to its boiling point. When a wire in the voltaic circuit is heated, the temperature frequently rises first, or most at one end; but it was shown by Faraday that this depends on adventitious circumstances, and is not due to any relation of positive or negative, as respects the current. Faraday has also shown (*Experimental Researches*, 853, *note*) that the same quantity of Electricity which, passed in a given time, can heat an inch of platinum wire of a certain diameter red hot, can also heat a hundred, a thousand, or any length of the same wire, to the same degree, provided the cooling circumstances are the same for every part, in all cases.

Fig. 174.



(408) It was Lieut.-General Pasley who first applied the heating power of the galvanic battery to a useful practical purpose. While engaged in operations on the river Thames, he was written to by Mr. Palmer (*Smee's Electro-metallurgy*, p. 297), who recommended him

to employ the galvanic battery, instead of the long fuse then in use, and after being put in possession of the method of operating, he immediately adopted it, and has since turned it to excellent account in the removal of the wreck of the Royal George at Spithead, as is well known.

(409) The destruction by gunpowder of the Round Down Cliff on the line of the South Eastern Railway, on Thursday, 26th January, 1843, is a splendid example of the successful application of a scientific principle to a great and important practical purpose. In this grand experiment, by a single blast, through the instrumentality of the galvanic battery, 1,000,000 tons of chalk were in less than five minutes detached and removed, and 10,000*l.* and twelve months' labour saved.

The following account is abridged from the Report in the *Times* newspaper:—"The experiment has succeeded to admiration, and as a specimen of engineering skill, confers the highest credit on Mr. Cubitt who planned, and on his colleagues who assisted in carrying it into execution. Everybody has heard of the Shakspeare Cliff, it would be superfluous, therefore, to speak of its vast height, were not the next cliff to it on the west somewhat higher: that cliff is Round-Down Cliff, the scene and subject of this day's operations. It rises to the height of 375 feet above high-water mark, and was, till this afternoon, of a singularly bold and picturesque character. As a projection on this cliff prevented a direct line being taken from the eastern mouth of Abbot's Cliff Tunnel to the western mouth of the Shakspear Tunnel, it was resolved to remove, yesterday, no inconsiderable portion of it from the rugged base on which it has defied the winds and waves of centuries. Three different galleries and three different shafts connected with them, were constructed in the cliff. The length of the galleries or passages was about 300 feet. At the bottom of each shaft was a chamber 11 feet long, 5 feet high, and 4 feet 6 inches wide. In each of the eastern and western chambers, 5,500 lbs. of gunpowder were placed, and in the centre chamber 7,500 lbs., making in the whole, 18,000 lbs. The gunpowder was in bags, placed in boxes: loose powder was sprinkled over the bags, of which the mouths were opened, and the bursting charges were in the centre of the main charges. The distance of the charges from the face of the cliff was from 60 to 70 feet. It was calculated that the powder, before it could find a vent, must move 100,000 yards of chalk, or 200,000 tons. It was confidently expected that it would move one million.

"The following preparations were made to ignite this enormous quantity of powder:—At the back of the cliff a wooden shed was

constructed, in which three galvanic batteries were erected. Each battery consisted of 18 Daniell's cylinders, and two common batteries of 20 plates each. To these batteries were attached wires which communicated at the end of the charge by means of a very fine wire of platinum, which the electric current as it passed over it made red hot to fire the powder. The wires, covered with ropes, were spread upon the grass to the top of the cliff, and then falling over it, were carried to the eastern, the centre, and the western chambers. Lieutenant Hutchinson, of the Royal Engineers, had the command of the three batteriès, and it was arranged that when he fired the centre, Mr. Hodges and Mr. Wright should simultaneously fire the eastern and western batteries. The wires were each 1000 feet in length, and it was ascertained by experiment that the current will heat platinum wire sufficiently hot to ignite gunpowder to a distance of 2,300 feet of wire.

"Exactly at twenty-six minutes past two o'clock, a low, faint, indistinct, indescribable, moaning subterranean rumble was heard, and immediately afterwards the bottom of the cliff began to belly out, and then almost simultaneously about 500 feet in breadth of the summit began gradually but rapidly to sink. There was no roaring explosion, no bursting out of fire, no violent and crashing splitting of rocks, and comparatively speaking very little smoke: for a proceeding of mighty and irrepressible force, it had little or nothing of the appearance of force. The rock seemed as if it had exchanged its solid for a fluid nature, for it glided like a stream into the sea, which was at a distance of 100 yards, perhaps more from its base, filling up several large pools of water which had been left by the receding tide. As the chalk, which crumbled into fragments, flowed into the sea without splash or noise, it discoloured the water around with a dark, thick, inky-looking fluid; and when the sinking mass had finally reached its resting place, a dark brown colour was seen on different parts of it which had not been carried off the land."

(410) The circumstance of so little smoke being seen attendant on the combustion of such a prodigious quantity of gunpowder, occasioned to many a good deal of surprise, and induced a belief that the whole of the gunpowder had not been fired; but when we consider that the smoke owes its visibility principally to the solid and finely divided charcoal* which is suspended in it, and that in passing through such an immense mass of limestone, it must have been *fil-*

* The principal gaseous results of the combustion of gunpowder are carbonic oxide, carbonic acid, nitrogen, and sulphurous acid; the solid residue consists of carbonate and sulphate of potassa, sulphuret of potassium, and charcoal.

tered as it were from this solid matter, our wonder at the absence of smoke on this occasion will cease.

(411) It was first pointed out by Mr. Grove (*Phil. Mag.* Dec. 1845; *Phil. Trans.* 1847) that there is a striking difference between the heat generated in a platinum wire by a voltaic current according as the wire is immersed in atmospheric air or in other gases. He found, by including a voltameter in the circuit, that the amount of gas yielded by the battery is in some inverse ratio to the heat developed in the wire, and by placing a thermometer at a given distance he further showed that the radiated heat was in a direct ratio with the visible heat. The following remarkable experiment was made. Two glass tubes of precisely the same length and internal diameter were closed with corks at each extremity; through the corks the ends of copper wires penetrated, and joining these were coils of fine platinum wire one-eightieth of an inch in diameter and 3·7 inches long when uncoiled. One tube was filled with oxygen and the other with hydrogen, and the tubes thus prepared were immersed in two separate vessels in all respects similar to each other, and each containing three ounces of water. A thermometer was placed in the water in each vessel, the copper wires were connected so as to form a continuous circuit with a nitric acid battery of eight cells, each cell exposing eight square inches of surface. Upon the circuit being completed, the wire in the tube containing the oxygen rose to a white heat, while that in the hydrogen was *not visibly ignited;* the temperature of the water, which at the commencement of the experiment was 60° Fahr. in each vessel, rose in five minutes in the water surrounding the tube of hydrogen from 60° to 70°, and in that containing the oxygen from 60° to 81°. Here then we have the same quantity of Electricity passing through two similar portions of wire immersed in the same quantity of liquid, and yet in consequence of their being surrounded by a thin envelope of different gases, a large portion of the heat which is developed in one portion appears to have been annihilated in the other. Similar experiments were made with other gases, and it was found that hydrogen far exceeded all other gases in its cooling effect on the ignited wire. The following was the order of the gases, both by direct experiment and by testing the intensity of ignition by the inverse conducting power of the wire as measured by the amount of gas in a voltameter included in the circuit.

Gases surrounding the wire.	Cubic inches of gas evolved in the voltameter per minute.
Hydrogen	7·7
Olefiant gas	7·0

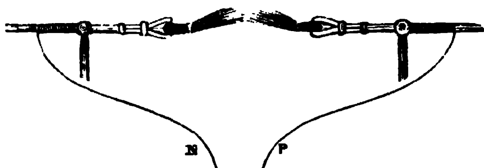
Gasses surrounding the wire.	Cubic inches of gas evolved in the voltameter per minute.
Carbonic oxide	6·6
Carbonic acid	6·6
Oxygen	6·5
Nitrogen	6·4

(412) Experiments were made by Mr. Grove in order to ascertain whether the phenomenon was occasioned by the varying specific heat of the media surrounding the wire, but the results were of a negative character. It then occurred to him that from the recognized analogy in chemical character of hydrogen to the metals, this gas may possibly possess a certain conducting power, and thus divert a portion of the current from the wire. An experiment, however, with a battery of 500 cells of the nitric acid arrangement failed to show the slightest conducting power either in this gas or in atmospheric air. Neither can the cooling effects of different gases be in any way connected with their specific gravities, since carbonic acid on the one hand and hydrogen on the other, produce greater cooling effects than atmospheric air; and olefiant gas, which closely approximates air, and is far removed from hydrogen in specific gravity, much more nearly approximates hydrogen, and is far removed from air in its cooling effect. On the whole, Mr. Grove is inclined to think that although influenced by the fluency of the gas, the phenomenon is mainly due to a molecular action at the surfaces of the ignited body and of the gas. We know that in the recognized effects of radiant heat, the physical state of the surface of the radiating or absorbing body exercises a most important influence on the relative velocities of radiation or absorption: thus black and white surfaces are strikingly contra-distinguished in this respect. "Why," he asks, "may not the surface of the gaseous medium contiguous to the radiating substance, exercise a reciprocal influence? Why may not the surface of hydrogen be as black, and that of nitrogen as white to the ignited wire?" Mr. Grove thinks this notion to be more worthy of consideration as it may establish a link of continuity between the cooling effects of different gaseous media, and the mysterious effects of surface in catalytic combinations and decompositions by solids such as platinum. Whatever may ultimately prove to be the real cause of the cooling influence of different gases, it is evident from Mr. Grove's experiments, that it is to be referred to some specific action of *hydrogen*, as the differences of effect of all gases other than hydrogen and its compounds, are quite insignificant when compared with the differences between the hydrogenous and other gases. Mr. Grove (the tendency of whose mind is to make practical applications of the facts disclosed

by science) suggests that the experiments now detailed may ultimately find some beneficial applications in solving the problem ot a safety-light for mines. A light which is just able to support itself under the cooling effect of atmospheric air, would be extinguished by air mixed with hydrogenous gas; indeed it is almost impossible to obtain the voltaic arc in hydrogen, though in nitrogen, which is equally incapable of combining with the terminals, it can be obtained without difficulty.

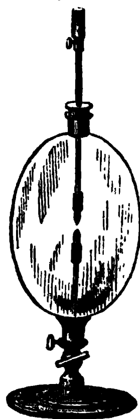
(413) Fig. 175 represents the appearance presented by the voltaic

Fig. 175.



flame between pencils of well-burnt boxwood charcoal, or which answers better, between pencils formed of that plumbago-like substance found lining the interior of long used coal-gas retorts. The arched form of the flame is owing to the ascensional force of the heated air. With respect to the charcoal light, it was noticed by De la Rive, with a Grove's battery of forty pairs (*Proc. Elect. Soc.*), that the luminous arc cannot be obtained between two charcoal points until after the two points have been in contact, and are heated around this point of contact. We may then by separating them gradually succeed in having between them a luminous arch an inch or more in length. Wood charcoal, which, after having been powerfully ignited, has been quenched by means of water, is that which gives the most beautiful light, on account of its conducting power being increased. Coke, though it succeeds as well as charcoal, does not give so brilliant and white a light: it is always rather bluish, and sometimes red. The transfer of particles of carbon from the positive to the negative pole, whilst the luminous arch is produced, is evident; but it is especially sensible *in vacuo*, Fig. 176. A cavity is observed to be formed in the point of the positive charcoal, presenting the appearance of a hollow cone, in which the solid cone, formed by the deposition of particles of carbon, might penetrate almost exactly. The phenomenon is almost the same in the air, except that the accumulation of carbon on the negative point is less, because a portion of the molecules burns in the transfer;

Fig. 176.



and the positive point presents only a flat instead of a hollow surface. This latter result probably arises from the combustion of the thin exterior of the hollow cone, which must be formed in air as well as *in vacuo*.

It is this more rapid consumption of the positive, than the negative carbon which has hitherto been one of the chief difficulties in the application of the electric light to practical illumination. Many attempts have been made to overcome this difficulty, but the most simple, perfect, and portable apparatus are those invented by M. Jules Duboscq and by M. Deleuil. The object to be attained is the maintenance of the charcoal terminals at a constant distance from each other. The lower or positive carbon is in Duboscq's lamp pressed upwards by a spring, the action of which is regulated by an endless screw set in motion by a lever, which is worked by an electro-magnet; this electro-magnet, enclosed in the pillar of the lamp, is only active when the circuit is complete, the moment therefore the charcoal terminals become separated, its iron keeper is detached, and the action of the spring, previously restrained by the screw, is put in force, and the carbon terminals are again brought into contact. The light is by this means kept tolerably constant. Deleuil's regulator is shown in Fig. 177. The negative carbon N is attached to a metal rod, which slides through the ball D with sufficient friction to remain permanent wherever it may be placed: the positive carbon P rises gradually by the operation of the voltaic current itself, so as to preserve a constant interval between N and P. The apparatus by which this is effected is situated beneath the frame of the instrument, and is shown separately in Fig. 178. A lever, A, is attached at one end to the spiral B, the other being retained between the points of two screws, so that the lever itself has freedom of motion vertically, but to a very small extent about the pivot L. E is an electro-magnet round which the battery current circulates. I is a steel spring in contact with one of the teeth of the vertical rod K, which carries the positive carbon P. C is an apparatus for regulating

Fig. 177.

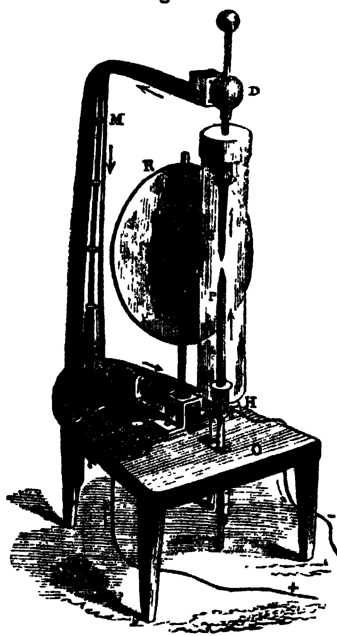
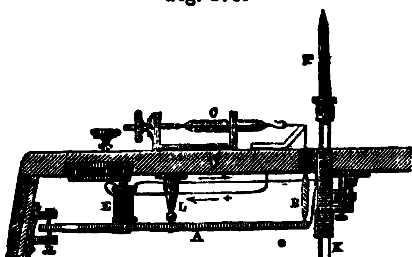


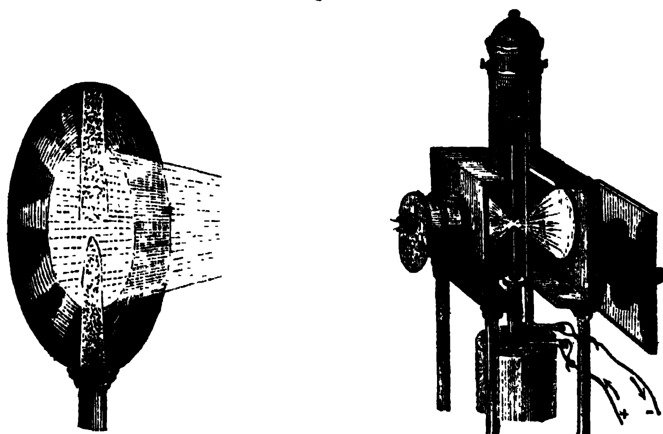
Fig. 178.



the spring B. Suppose now the voltaic current to pass with its full intensity round the electro-magnet E, the armature on the lever will be immediately attracted, the resistance of the spiral R will be overcome, that end of the lever will descend, and the rod K will be restrained or trigged by the spring I: as the distance between the ignited carbon N P increases, the current circulating round the electro-magnet gradually diminishes, till the force of the spiral R predominates; that end of the lever now rises, and the spring I forces the rod K upwards, the carbons are thus again brought into contact, the current again circulates round the electro-magnet, the rod K is again restrained, and in this way a series of periodic movements is kept up, the result of which is to keep the carbon terminals constantly within the proper distance for the passage of the disruptive discharge. To preserve the ignited terminals from the cooling influence of the external air, they are enclosed in a glass cylinder and a metallic reflector R, which may be removed at pleasure, is placed behind them.

Fig. 179 represents the arrangement of Foucault's experiment of

Fig. 179.



throwing the image of the carbon terminals during ignition by means of a lens on a screen. It shows in a beautiful manner the gradual wearing away of the positive and the increase of the negative carbons. The small globules or specs observed on the charcoal arise from the

fusion of the minute quantities of silica contained in the coal. When the voltaic current is thrown on, the *negative* carbon first becomes luminous, but the light from the positive is afterwards much the most intense, and as this is the terminal which wears away, it should be somewhat thicker than the other.

(414) On reflecting on the remarkable difference between the heating effects of the positive and negative wires of the voltaic battery (405), it occurred to Mr. Grove (*Phil. Mag.* vol. xvi. p. 478) that it might be due to the interposed medium, and that were there any analogy between the state assumed by voltaic *electrodes* in elastic media, and that which they assume in *electrolytes*, it would follow that the chemical action at the positive electrode in atmospheric air would be more violent than that at the negative, and that if the chemical action were more violent, the heat would necessarily be more intense.

By experiments performed with an arrangement of thirty-six pairs of his nitric acid battery, Mr. Grove established the following points:—

1°. If zinc, mercury, or any oxidable metal constitute the positive electrode, and platinum the negative one, in atmospheric air, while the disruptive discharge is taken between them, a voltameter inclosed in the circuit, yields considerably more gas than with the reverse arrangement.

2°. In an oxidating medium, the brilliancy and length of the arc are (with certain conditions) directly as the oxidability of the metals between which the discharge is taken.

3°. In an oxidating medium the heat and consumption of metal is incomparably greater at the *anode* than at the *cathode.*

4°. If the disruptive discharge be taken in dry hydrogen, in azote, or in a vacuum, no difference is observable between the heat and light, whether the metals be oxidable or inoxidable, or whether the oxidable metal constitute the positive or negative electrode.

5°. The volume of oxygen absorbed by the disruptive discharge taken between a positive electrode of zinc and a negative one of platinum in a vessel of atmospheric air, is equal to that evolved by a voltameter included in the same circuit.

(415) A remarkable analogy between the electrolytic and disruptive discharges is here presented, but there are two elements which obtain in the latter which have little or no influence on the former, viz., the volatility and state of aggregation of the conducting body. This was shown remarkably in the case of iron, which in air or in oxygen gave a most brilliant voltaic arc, while in hydrogen, or a vacuum, with the same power, a feeble spark only was perceptible at

the moment of disruption. Mercury, on the other hand, gave a tolerably brilliant spark in hydrogen, azote, or a vacuum, and one more nearly approaching to that which it gives in air.

(416) It has been established by Faraday, that in electrolysis, a voltaic current can only pass by the derangement of the molecules of matter; that the quantity of the current which passes is directly proportional to the atomic disturbance it occasions: he deduces from this, that the quantity of Electricity united with the atoms of bodies is as their equivalent numbers, or in other words, that the equivalent numbers of different bodies serve as the *exponents* of the comparative quantities of Electricity associated with them (*Experimental Researches*, 518, 524, 732, 783, 836, 839). "Now," observes Mr. Grove, "what takes place in the disruptive discharge? When we see dazzling flame between the terminals of a voltaic battery, do we see Electricity, or do we not rather see matter, detached, as Davy supposed, by the mysterious agency of Electricity, and thrown into a state of intense chemical or mechanical action? Matter is undoubtedly detached during the disruptive discharge, and this discharge takes its tone and colour from the matter employed. Now, as this separation is effected by Electricity, Electricity must convey with it either the identical quantity of matter with which it is associated, or more or less; more it can hardly convey, and if less, some portion of Electricity must pass in an insulated state or unassociated with matter, and some with it." Mr. Grove proceeded to institute some experiments with a view of determining whether the quantity of matter detached by the voltaic disruptive discharge was definite for a definite current, or bore a direct equivalent relation to the quantity electrolyzed in the liquid portions of the same circuit. The great difficulties attending such an inquiry defied accurate results; but sufficient was gathered to afford strong grounds for presumption that the separation of matter in the voltaic arc *is* definite for a definite quantity of Electricity, and that the all important law of Faraday is capable of much extension; and uniting this view with the experiments of Faraday on the identity of Electricity from different sources, and with those of Fusinieri on the statical electrical discharge, it would follow as a corollary that every disturbance of electrical equilibrium is inseparably connected with an equivalent disturbance of the molecules of matter.

(417) In a paper published in the Transactions of the Royal Society (*Phil. Trans.* part i., 1847), De la Rive has communicated some further researches on the voltaic arc, and on the influence which magnetism exerts on it, and on bodies transmitting interrupted electric currents. The length of the luminous arc has a relation to

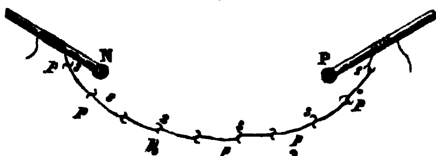
the greater or less facility with which the substances composing the electrodes possess of being se-gregated, a facility which may depend upon their temperature diminishing their cohesion, upon their tendency to oxidize, upon their molecular state, and, lastly, upon their peculiar nature. *Carbon* is one of the substances which produces the longest luminous arc, a property which it derives from its molecular condition, which renders it particularly friable. When a *plate* of platinum was made the positive electrode to a *point* of platinum, the negative electrode of a nitric acid battery of fifty pairs in rarefied air, a circular spot presenting the appearance of one of Nobili's coloured rings was formed on the plate, the result evidently of the oxidation of the platinum: it was not so vivid in ordinary air. When the plate was negative, and the point positive, the former became covered with a white circular spot formed of a vast number of minute grains of platinum, which having been raised to a high temperature, remained adhering to the surface. This also was larger in the pneumatic vacuum. With a point of coke negative, and a plate of platinum positive, an arc more than twice as long as before was obtained, and the light, instead of being a cone, was composed of a multitude of luminous jets diverging from different points of the plate, and tending to various parts of the point of coke; the heat was also much greater, and the platinum plate was soon perforated. With the point of coke positive, and the platinum plate negative, the heat was still very great though the arc was less. With a platinum plate and *zinc* point the effects were most brilliant, white oxide of the metal being precipitated (in air) upon the platinum plate, and a black deposit in the vacuum of the air pump. An *iron* point gave in air a deposit of red oxide, and in rarefied air a deposit of black oxide. With a point and plate of *copper* the arc had a beautiful green colour. When *mercury* was used the luminous effect was most brilliant, the metal was excessively agitated, rising up in the form of a cone when it was positive, and sinking considerably below the positive point when it was negative.

When the arc is formed, it is those parts of the circuit which present the greatest resistance to the current which become the hottest. The metal, which is the worst conductor, is the most strongly heated. When both the conductors are of the same material the development of heat is not uniform, it being much greater on the positive side. With a silver positive and platinum negative point, the latter becomes incandescent, the silver being much less heated; with two silver or two platinum points the positive one alone becomes incandescent throughout its whole length.

In consequence of its good conducting power, a voltaic battery will

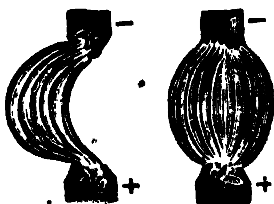
heat to redness a greater length of silver wire than of platinum; nevertheless, if a compound wire be formed of several alternate links of platinum and silver, as shown in Fig. 180, and disposed between the poles of a powerful battery, the platinum links will become red hot during the passage of the current, while the alternate silver links will remain dark. The charge, which passes freely along the silver, meets with resistance enough in the platinum, to produce ignition.

Fig. 180.



(418) *Influence of magnetism on the voltaic arc.*—It was first observed by Davy that a powerful magnet acts upon the voltaic arc, as upon a moveable conductor traversed by an electric current; it attracts and repels it, and this attraction and repulsion manifests itself by a change in the form of the arc, which may even become broken by too great an attraction or repulsion. Fig. 181 represents the voltaic flame between two cylinders of plumbago, and Fig. 182 the curved form which it assumes under the influence of a magnetic pole.

Fig. 182. Fig. 181.



De la Rive found that an arc cannot be formed between two iron points when they are magnetized, unless they are brought very close, and then, instead of a quick luminous discharge, sparks fly with noise in all directions, as if the transported particles disengaged themselves from the positive electrode with great difficulty. The noise is analogous to the sharp, hissing sound of steam issuing from a locomotive, and this is the case whatever may be the nature of the negative electrode. When a plate of platinum was placed upon one of the poles of a powerful electro-magnet, and a point of the same metal vertically above it, and the voltaic arc produced between the point and the plate, the former being positive and the latter negative, a sharp hissing sound was heard; when the conditions were reversed the effect was totally different; the luminous arc no longer maintained its vertical direction when the electro-magnet was charged, but took an oblique direction, as if it had been projected outwards towards the edge of the plate; it was broken incessantly each time, being accompanied by a sharp and sudden noise similar to the discharge of a Leyden jar. The direction in which the arc was projected depended on that of the current producing it, as likewise on the position of the plate on one or other of the two poles. When a *copper*

plate was made the positive electrode on a pole of the electro-magnet, that portion of the surface lying underneath the negative point presented a spot in the form of a helix, as if the metal melted in this locality had undergone a gyratory motion round a centre, at the same time that it was uplifted in the shape of a cone towards the point. The curve of the helix was fringed with tufts similar to those which mark the passage of positive Electricity in a Leyden jar. When the plate was negative, and the point positive, no such marks were produced. With two copper points, the hissing sound was so loud, as to bear a resemblance to distant discharges of musketry, but for this the magnet was required to be very powerful, and the battery power intense. The hissing sound was the result of the easy and continuous transport of matter more or less liquefied from the positive electrode, while the detonations were probably the effect of the resistance opposed by the same matter, to the disintegration of its particles when it was not sufficiently heated.

(419) The magnet causes these effects by producing a change in the molecular constitution of the matter of the electrode, or rather in the highly diffused matter which forms the voltaic arc. That the magnet really does exert a molecular modification of the particles of matter subjected to its influence, is proved by the *sounds* produced when electric currents are sent through metallic bars when placed on the poles of the electro-magnet; bars of iron, tin, zinc, bismuth, and even of lead, emit distinct sounds when traversed by a current from five to ten pairs of the nitric acid battery, while resting on the pole of a powerful magnet; copper, platinum, and silver bars do the same, and mercury enclosed in a tube of glass emits an intense sound. De la Rive also found that helices of metals were sonorous, as were dilute sulphuric acid, and solution of common salt. It is the opinion of De la Rive that the influence of magnetism on all conducting bodies impresses on them, as long as it lasts, a molecular constitution similar to that which iron and generally all bodies susceptible of magnetism possess naturally.

(420) For experiments on the sounds produced in metallic wires by the passage of a voltaic current through or round them, a sounding board may be employed on which the wires or rods are kept in a state of tension, by a weight of nine or ten pounds; the electric current may be sent through the wires, or through helices of copper wire surrounding but not touching them; the current must not be continuous, but broken at regular intervals by means of a mechanical contrivance called a commutator. Those metals which are the *worst* conductors give the most pronounced effects, but iron far surpasses every other metal, after which comes platinum. The sound given out by a well-annealed iron wire, when it transmits the current, is very

strong, greatly resembling the sound of church bells in the distance. De la Rive suggests that it might perhaps be advantageously employed in the electric telegraph. The tone of the sound varies with the velocity with which the discontinuous currents succeed each other; when the succession is very rapid, the sound resembles the noise which the wind makes when it blows strongly.

(421) The vibratory motion which results from the magnetization and demagnetization of soft iron is shown by the following beautiful experiment. In the interior of a bobbin, or a bottle surrounded with a wire rolled into a helix, are placed some very small discs or filings of iron; when the discontinuous current traverses the wire of the helix, the discs or filings are seen to be agitated, and to revolve round each other in the most remarkable manner, the filings have the perfect appearance of being in ebullition; if the current is intense, they dart in the form of jets like so many fountains. The motion of the filings is attended with a noise similar to that of a liquid when it is boiling.

(422) The heating power of the voltaic flame is so intense that the most refractory substances succumb to it; platinum, iridium, and titanium, which withstand the heat of the most powerful furnace, are readily fused. To exhibit these effects a small cavity is bored in the positive gas coke electrode, which serves as a crucible, Fig. 183; into this the metal is placed, and the current is transmitted from a battery of not less than twenty of Grove's or Bunsen's arrangements, as shown in the figure; the metals are not only fused, but are actually converted into vapour and disappear.

Fig. 183.



(423) The conducting powers of metals, or their capacity for transmitting Electricity, have been estimated very differently by different experimenters, as will be seen by the following table, in which the relative lengths of wires which, with equal diameters, conduct the same quantity of Electricity, are expressed in numbers.

BECQUEREL.		OHM.		DAVY.	
Copper	100	Copper	100	Silver	109·1
Gold	93·6	Gold	57·4	Copper	100·
Silver	73·6	Silver	35·6	Gold	72·7
Zinc	28·5	Zinc	33·3	Lead	69·1
Platinum	16·4	Brass	28·0	Platinum	18·2
Iron	15·8	Iron	17·4	Palladium	16·4
Tin	15·5	Platinum	17·1	Iron	14·6
Lead	8·3	Tin	16·8		
Mercury	3·45	Lead	9·7		
Potassium	1·33				

LENZ. AT 32° FAHR.	
Silver	136·25
Copper	100·
Gold	79·79
Tin	30·84
Brass	29·33
Iron	17·74
Lead	14·62
Platinum	14·16

REISS.	
Silver	148·74
Copper	100·00
Gold	88·87
Cadmium	38·35
Brass	27·70
Palladium	18·18
Iron	17·66
Platinum	15·52
Tin	14·70
Nickel	13·15
Lead	10·32

POUILLET.	
Gold	103·5
Copper	100·0
Platinum	22·5
Brass	15·2 / 23·4
Cast Steel	13·0 / 20·8
Iron	15·6 / 18·2
Mercury	2·6

Harris gives the following order (*Trans. Royal Soc. Edinburgh*, 1834) but does not express the relative conducting powers numerically;—silver, copper, zinc, gold, tin, iron, platinum, lead, antimony, mercury, bismuth. His mode of examination was to pass the current from the battery through equal lengths and sizes of the respective wires, his electro-thermometer (Fig. 94) being included in the circuit; the conducting powers of the metals, which were kept cool by being surrounded with cold water, were estimated by the height to which the liquid rose in the stem of the instrument. By thus experimenting Harris arrived at the following deductions.

1°. That for certain and given small forces, the differences in the conducting powers vanish, each metal being equally efficient. 2°. The differences in conducting powers become more apparent within a certain limit as the force of the battery increases. 3°. The principle arrived at by Mr. Children, that the heat evolved by a metal whilst transmitting a charge is in some inverse ratio of the conducting power, is only true in employing charges within the limit of the transmitting power, and when the force is *great*, the best conductor is most heated, when *less*, the inferior conductor.

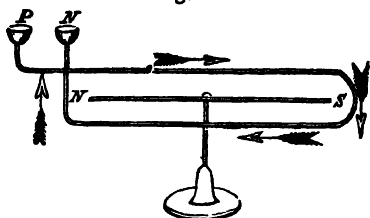
(424) Some other results obtained by Harris with his electro-thermometer are worth recording. The heat excited in a metallic wire by a simple voltaic arrangement is exactly in the *inverse ratio* of the distance between the plates, and directly as the quantity of metal immersed in the exciting liquid. When the wire is very thin, it is more heated by a feeble current than a thick one, but with an increased power, the thick wire is the most heated, the thin wire being unable to transmit the whole of the power. The influence of heat in diminishing the conducting power of a metal is shown by including a length of about 6 inches in the circuit together with the electro-thermometer, and when the liquid is at its greatest height, heating it by a spirit lamp, the fluid immediately falls, and continues

to descend, as the wire becomes more and more heated; on removing the lamp, and allowing the wire to cool, the liquid recovers its former elevation; when, on the contrary, the wire is artificially cooled by pouring ether on it, the effect on the electrometer is increased. A wire that is heated to redness through its entire length by a voltaic battery, may be fused by suddenly dipping a portion of it in cold water, which is the common mode of demonstrating the influence exerted by heat on the conducting power of metals. With a series of 160 cells of the constant battery, Walker was unable to heat platinum wire $\frac{1}{80}$th of an inch in diameter, though sixty inches of $\frac{1}{10}$th of an inch in diameter were made red-hot. But with the same battery arranged in a different manner, thirty-four inches of the thicker, and only twenty-seven of the thinner were heated. The *size* of the wire heated by a battery depends on the extent of the surface of the electro-motive elements, the *length* heated depends on the number of the series, the quantity of Electricity remaining the same. This has been verified by Walker, in his experiments with the constant battery above referred to (*Trans. Elect. Soc.* p. 69), and is precisely what theory would lead us to expect. Faraday found (*Ex. Resear.* 853, *note*) that the same quantity of water was decomposed by a battery, whether half-an-inch or eight inches of red-hot wire were included in the circuit, and he observes that a fine wire may even be used as a rough but ready regulator of a voltaic current; for if it be made part of the circuit, and the larger wires communicating with it be shifted nearer to, or further apart, so as to keep the portion of wire in the circuit sensibly at the same temperature, the current passing through it will be nearly uniform.

(425) *Magnetic phenomena.*—The influence of magnetism on the voltaic arc has already been alluded to; the consideration of the mutual relations of the magnetic and electrical forces belongs to another division of our subject, and we only refer to them here for the purpose of describing some instruments which are much used for determining the intensity of hydro-electric currents. These instruments are called *galvanometers* or *galvano-multipliers*, and are founded on the important discovery of Oersted, made in the year 1819. The fundamental fact observed by this philosopher was, that when a magnetic needle is brought near the connecting medium (whether a metallic wire, or charcoal, or even saline fluids, of a closed voltaic circle), it is immediately deflected from its natural position, and takes up a new one, depending on the relative positions of the needle and wire. If the connecting medium is placed horizontally *over* the needle, that pole of the latter which is nearest to the *negative* end of the battery always moves *westward;* if it is placed *under*, the same

pole moves to the *east*. If the connecting wire is placed parallel with the needle, that is, brought into the same horizontal plane in which the needle was moving, then no motion of the needle in that plane takes place, but a tendency is exhibited in it to move in a vertical circle, the pole nearest the *negative* side of the battery being depressed when the wire is to the *west* of it, and elevated when it is placed on the *eastern* side. If the battery current be sent above and below the needle at the same time, but in opposite directions, the deflection is more powerful, for the current traversing the wire above the needle conspires equally with the current passing along the wire below, to deflect the needle from its natural position, and to bring it into a new one, nearer to right angles to the plane of the wire.

Fig. 184.



(426) If, instead of simply passing once over and once under the needle, the conducting wire be caused to make a great number of convolutions, the deflecting power of the current will be proportionately increased, and an instrument will be obtained by which very feeble currents may be readily detected. This then is the principle of the *galvanometer*, the simplest form of which is shown in Fig. 184, but to which, to adapt it to the detection of very minute currents, various forms have been given; in *all* the convolutions of the wire are multiplied, and the lateral transfer of Electricity prevented by coating it with silk or sealing-wax.

Fig. 185.

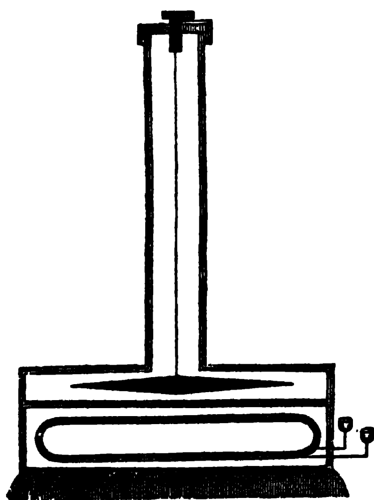


Fig. 185 is a vertical section of the torsion galvanometer of the late Professor Ritchie. The following is his description of its construction:—"Take a fine copper wire, and cover it with a thin coating of sealing-wax, roll it about a heated cylinder, an inch or two in diameter, ten, twenty, and any number of times, according to the delicacy of the instrument required. Press together the opposite

sides of the circular coil till they become parallel, and about an inch, or an inch and a half long. Fix the coil in a proper sole, and connect the ends of the wires with two small metallic cups, for holding each a drop of mercury. Paste a circular slip of paper, divided into equal parts horizontally, on the upper half of the coil, and having a black line drawn through its centre, and in the same direction with the middle of the coil. Fix a small magnet, made of a common sewing needle, or piece of steel wire, to the lower end of a fine glass thread, while the upper end is securely fixed with sealing-wax in the centre of a moveable index, as in the common torsion balance. The glass thread should be inclosed in a tube of glass, which fits into a disc of thick plate glass, covering the upper side of the wooden box containing the coil and magnetic needle." (*Phil. Trans* 1830, p. 218.)

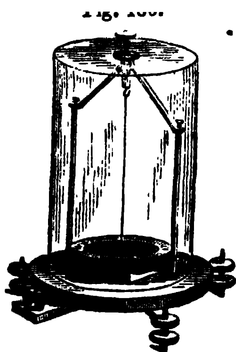
(427) The sensibility of this instrument is very much increased by neutralizing the magnetic influence of the earth, by employing two needles, which was first done by Professor Cumming of Cambridge, and afterwards on an improved principle by Nobili. The neutralizing needle in his instrument is attached to the principal one; placing them one above another and parallel to each other, but with their poles in opposite directions. They are fixed by being passed through a straw, suspended from a thread. The distance between the needles is such as to allow the upper coil of the wires to pass between them, an opening being purposely left, by the separation of the wires at the middle of that coil, to allow the middle of the straw to pass freely through it. A graduated circle on which the deviation of the needle is measured, is placed over the wire, on the upper surface of the frame of the instrument, having an aperture in its centre for the free passage of the needle and straw. The whole of this arrangement will be easily understood, by imagining another needle to be suspended to the one above the coil in Fig. 185, moving *within* the wire, and having its poles turned the reverse of those of the upper needle. The instrument as thus constructed is called the astatic needle galvanometer. In Nobili's instrument, the frame was twenty-two lines long, twelve wide, and six high. The wire was of copper covered with silk, one-fifth of a line in diameter, and from twenty-nine to thirty feet in length, making seventy-two revolutions round the frame. The needles were twenty-two lines long, three lines wide, a quarter of a line thick, and they were placed on the straw five lines apart from each other.

(428) The advantages of Nobili's instrument consist in the directive force, arising from the influence of the earth's magnetism being nearly balanced, and a double rotatory tendency being given to the

needles. The lower needle is acted upon by the sum of the forces of the currents in every part of the coil, and the upper needle is acted upon by the excess of force in the upper current which is nearest to it, which force, of course, acts in a direction the reverse of that in which it acts upon the lower needle, being situated on the opposite side; but since the poles are also in a reversed position, the rotatory tendency becomes the same in both needles. M. Lebailiff has extended the principle of Nobili's galvanometer, by employing four needles, two within the coil, having their poles similarly situated, and one above, and one below, having their poles reversed. He likewise employs five parallel wires, each sixty feet long for the coil, instead of one length of three hundred feet; by this means the current is divided into five parts, and made to flow through five different channels, with the alleged advantage of increasing the quantity, and diminishing the intensity of the Electricity; it is not decided whether this is the case, nor is the advantage of employing four needles sufficiently obvious.

Fig. 186 represents an elegant modification of Nobili's galvanometer. The bobbin is surrounded with some two or three thousand turns of very fine and well-insulated copper wire. The needles are suspended by a single fibre of bleached and baked silk. When the instrument is not in use the upper needle rests on a graduated card, from which it is raised when about to be put in action, by a simple mechanical contrivance, at the top of the glass shade. The axis joining the two needles must be brought exactly in the centre of the card, which is easily effected by means of adjusting screws. The upper needle is brought exactly to zero of the scale by turning the card, by means of a button, underneath the base of the instrument. A good galvanometer should not make more than two oscillations a minute, and should return exactly to zero. It is almost needless to say, that the table on which it stands should contain no iron, and that all iron vessels should be removed, as far as possible, from its neighbourhood. It is covered with a glass case, to protect it from currents of air. So exquisite a test of the presence of minute quantities of Electricity, is a delicate galvanometer, that, by it, Schoenbein (*Pog. Ann.* xlv. p. 263) was able to prove a change in the composition of chloride of cobalt, when that salt in solution was changed blue by the action of heat.

Fig. 186.



(429) The following illustration of the increase of the power of

the current by employing the astatic system, is given by Peschell (*Elements of Physics*, vol. iii. p. 107): Suppose that the multiplier wire wound 333 times, then the original current would act on the *lower* needle with a force of 666, and on the *upper* with a force of 333 times, what it would have possessed had the wire made but a single circuit; adding both together, with a force 999, or 1000 times as great. Both needles made, with a similar position of their poles, 57 vibrations in a minute, an astatic needle only 9. As the directing force of the earth's magnetism is proportional to the squares of these numbers, in the common needle this force will be 3248, and in the astatic needle 81; in the latter therefore it is 40 times less, and by consequence the electric current acts with 40 times the force upon it. The deflecting power of the original current will therefore be increased by this galvanometer $1000 \times 40 = 40{,}000$ times. The two needles in the astatic galvanometer, should be as similar as possible, but not of precisely the same magnetic power, a slight degree of directive force being necessary in the system, otherwise it would remain in equilibrium in all azimuths. The frame on which the wire is wound should not be fixed, but moveable upon an axis, so that by a simple mechanical contrivance it may be brought into any required position with respect to the needles.

(430) The sensibility of a galvanometer is judged of by the slowness of the oscillations of its magnetic system; it may be considered sufficiently delicate, if they are at the rate of *one a minute:* but it not unfrequently happens that either from too strong a current, being sent through the instrument;—from the contiguity of a magnetic bar;—from the reaction of the magnetism of the two needles; or from some difference in their dimensions, and the quality of the steel; the galvanometer after a time loses a portion of its sensibility. By subjecting the needles to the following treatment, (Matteucci) the original delicacy of the instrument may be restored, but the operation requires considerable care and tact, and it is not an unusual occurrence, to spend whole days in the arrangement of a galvanometer for a course of delicate experiments. The first thing to be done is to note carefully the duration of an oscillation, then to ascertain which is the weaker of the two needles, for this purpose the upper one is first removed; if now the system remain in its position, it is clear that the needle removed is more feeble than the other; if, on the other hand, the needle which remains, returns of itself, it is evident that the needle taken away was the stronger of the two. The weak needle is then re-magnetized by passing a small bar magnet a few times along it from end to end, taking especial care not to arrest the motion of the bar or to return it on itself: the needle is

then returned to its place, and the duration of an oscillation of the system again determined; if it has become greater, a proof is obtained that the sensibility of the galvanometer has been increased: should too much magnetism have been given to the needle, a portion must be taken away by reversing the motion of the magnetising bar along it. This is a nice operation and frequently gives a good deal of trouble.

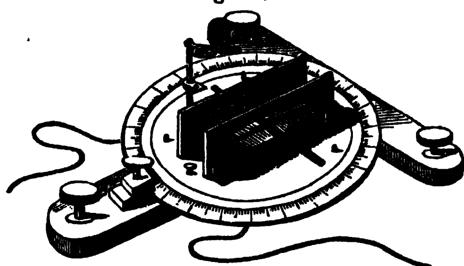
(431) It is usual for the maker of a galvanometer to mark on the scale, an indication by which the experimenter is enabled to ascertain from the direction of the deviation of the needle, the direction of the current. For this purpose we find marked on the scale two letters A and B, the same two letters are also marked on the side of the two extremities of the galvanometer. By a first experiment, the operator determines once for all, by means of a single electro-motive element, zinc and copper for instance, to which letter the point of the needle is carried according as the current enters into the wire of the instrument by the extremity A or B; of course in the single voltaic pair the current is from the copper to the zinc.

(432) Before commencing a series of experiments, the marked indications of the galvanometer should be verified, which may easily be done by plunging the extremities of two wires, platina and copper, into distilled water, and allowing the current of Electricity thereby determined to pass through the instrument, the direction of the current is from the platinum to the copper, through the galvanometer.

(433) In his researches in electro-physiology, M. Dubois Reymond employed a galvanometer containing 4560 coils of copper wire, and he has more recently had an apparatus constructed by M. Sauerwald of Berlin, with from 25,000 to 30,000 coils; with this instrument, he detected the existence of electric currents in nerves and in muscles; but to fit it for these delicate investigations, it was necessary to make corrections for certain irregularities of action, arising from two causes; *first*, from the axes of the needles never being rigorously parallel, in consequence of which the system is never accurately in the meridian; and *second*, from the impossibility of obtaining copper wire absolutely free from iron, the consequence of which is that the needle never stands exactly at zero. The correction applied by Dubois Reymond is an improvement of that originally adopted by Nobili, and consists in placing in the interior of the galvanometer, facing the zero, a small magnetized fragment $\frac{1}{25}$ of an inch in length, which compensates the disturbing action as long as the needles are near zero, but the action of which is null, as soon as they move through a few degrees.

(434) The *Sine* Galvanometer (Fig. 187), consists of a single magnetized needle surrounded with a coil which is moveable on its axis; it acts on the principle that *the intensity of the current varies as the sine of the angle of deflection*, and is applicable rather to the determination of the intensity of strong currents, than to the detection of weak ones. The instrument is placed in the magnetic meridian, and when the needle is deflected by the current, the coil is turned until it again coincides with the new direction of the needle, the exact parallellism of the needle and coil, being determined with the aid of a lens. The number of degrees which it was necessary to turn the coil from the zero point to adjust it to the new position of the needle, is read off on the graduated scale surrounding the coil. This is the exact measurement of the angle which the needle forms with the magnetic meridian, and also of the intensity of the current, by which the needle has been deviated; but this is also equal to the horizontal force of terrestrial magnetism, in virtue of which, the needle tends to return to the magnetic meridian, and this being equal to the *sine of the angle of deflection*, the intensity of the current is of course the same, and its value may be determined by reference to a table of natural sines.

Fig. 187.



(435) Professor Callan's sine galvanometer (*Phil. Mag. N. S.* vol. vii. p. 73), consists of a mahogany circle 2 feet 4 inches in diameter, and nearly 2 inches thick, in the circumference of which is turned a groove ½ an inch wide and 3½ inches deep; of seven concentric coils of ⅛ of an inch copper wire in the groove, and well insulated from each other; of a strong frame in which the circle is moveable on an axis and always kept in a vertical position; and of a compass-box, which, by means of a slide 3 feet long, and at right angles to the circle at its centre, may be moved in a direction perpendicular to the circle to the distance of 3 feet from it, so that the centre of the needle, which is a bar 5½ inches long, will always be in the axis of the coil, and that the line joining the N. and S. points of the compass-box will be always parallel to the horizontal diameter of the mahogany circle and coil. From this description it is evident that (no matter where the compass-box is placed on the slide) the needle is parallel to the mahogany circle and coil, or perpendicular to their axis whenever it points to 0°. Hence, if a voltaic current sent through the coil deflect the needle, and if the circle and coil be turned round so

as to follow the needle until it points to 0°, the needle, no matter where it may be placed on the slide, will then be parallel to the coil and perpendicular to its axis.

The effective part of the earth's magnetism in impelling the needle to the magnetic meridian is also exerted in the direction of a perpendicular to the needle or of the axis of the coil, but opposite to that in which the magnetic force of the coil acts. Since the needle is kept at rest by these two forces acting in opposite directions, they must be equal. But the effective part of the earth's magnetism in impelling the needle to the magnetic meridian varies as the sine of the angle which it makes with the meridian; therefore the magnetic power of the current flowing through the coil also varies as the sine of the angle which the needle, when it points to 0°, makes with the magnetic meridian. If the connection with the battery be broken, the needle will immediately return to the magnetic meridian. The graduated circle of the compass-box will give the number of degrees the needle was deflected from the magnetic meridian. For measuring the angle of deviation, a graduated circle about 13 inches in diameter is used; it is attached to the upper part of the mahogany circle, and at right angles to it, and to the axis about which it is moveable. When the current is sent through 7 coils, the deflection is so great, that only very feeble currents can be measured on the sine galvanometer. When the needle is in the centre of the coil, this galvanometer, used as a sine instrument, large as is its diameter, is incapable of measuring the power of a current produced by a single circle of the cast iron battery: but by sliding the compass-box and needle 2 or 3 feet from the coil, a current of very great power can be measured.

(436) The *Tangent* Galvanometer (Figs. 188 and 189) consists of a large circle or hoop of copper ribbon covered with silk, fixed verti-

Fig. 188.

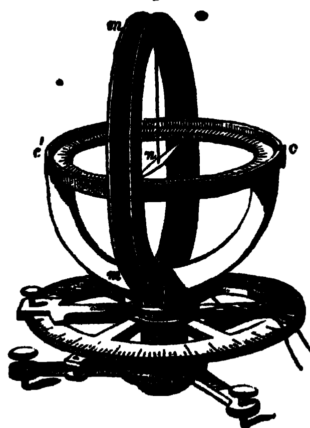
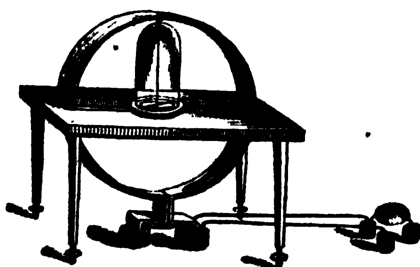


Fig. 189.



cally upon a graduated circle, exactly in the centre of which is placed, either by suspension by a silk thread, or on a cap resting on a pivot, a very short but intensely magnetized needle. The hoop is placed exactly in the magnetic meridian, and when the current is transmitted through it, the needle deviates, and the force of the current is proportional *to the tangent of the angle of the needle's declination*, whence the name given to the instrument. The needle is provided transversely with a long light copper needle by means of which the angle is measured. This instrument is not so sensitive as the sine galvanometer, but is applicable to currents of very high intensity. The tangent of the angle of deflection may be learned, without calculation, by reference to the table of natural tangents. An instrument called the *differential* galvanometer has been used for the determination of the relative force of two currents. It consists of a galvanometer with two perfectly similar wires wound round the same frame; now, if two currents of precisely the same intensity be sent in opposite directions through these wires the needle will obviously remain at zero, but if one current be more powerful than the other, the needle will move, indicating the strongest current, and showing by the amplitude of the deviation, by how much, the strongest current exceeds the weakest.

(437) For the detection of currents of small intensity, such as those produced by thermo-electric action, neither of the galvanometers above described is adapted, the length and the thinness of the wire opposing too great a degree of resistance to the passage of such feeble forces. The wire for such purposes should make but few turns round the needle, and should be at least $\frac{1}{30}$th of an inch in thickness, or, as Fechner recommends, should consist of a single strip of copper, and an astatic needle having the freest possible motion.

(438) A large and very sensible thermoscopic galvanometer was invented by Dr. Locke, professor of chemistry in the medical college of Ohio, and by him communicated to the Phil. Mag., in August, 1837. The object proposed by Dr. Locke in the invention of this instrument was to construct a thermoscope so large that its indications might be conspicuously seen on the lecture-table by a numerous assembly, and at the same time so delicate as to show extremely small changes of temperature. How far he succeeded, will appear from the following very popular experiment he was in the habit of making with it. By means of the warmth of the finger applied to a single pair of bismuth and copper discs, there was transmitted a sufficient quantity of Electricity to keep an eleven-inch needle weighing an ounce and a half, in a continued

revolution, the connexions and reversals being properly made at every half turn.

The greater part of this effect was due to the *massiveness* of the coil which was made of a copper fillet about fifty feet long, one-fourth of an inch wide, and one-eighth of an inch thick, weighing between four and five pounds. This coil was not made in a pile at the diameter of the circle in which the needle revolved, but was spread out, the several turns lying side by side and covering almost the whole of that circle above and below. It was wound closely in parallel turns on a circular piece of board eleven and a half inches in diameter, and half an inch in thickness, covering the whole of it except two small opposite segments of about ninety degrees each; on extracting the board, a cavity of its own shape was left in which the needle was placed.

The copper fillet was not covered by silk, or otherwise coated for insulation, but the several turns of it were separated at their ends by veneers of wood just so far as to prevent contact throughout. In the massiveness of the coil this instrument is perhaps peculiar, and by this means it affords a free passage to currents of the most feeble intensity, enabling them to deflect a very heavy needle. The coil was supported on a wooden ring furnished with brass feet and levelling screws, and surrounded by a brass hoop with a flat glass top or cover, in the centre of which was inserted a brass tube for the suspension of the needle by a cocoon filament. The needle was the double astatic one of Nobili, each part being about eleven inches long, one-fourth wide, and one-fortieth in thickness. The lower part played within the coil, and the upper one above it, and the thin white dial placed upon it, thus performing the office of a conspicuous index underneath the glass. For experiments in which large quantities of Electricity are concerned, this instrument is quite unfit: but it is well adapted to show to a class, experiments on radiant heat with Pictet's conjugate reflectors, in which the differential, or air thermometer, affords to spectators at a distance but an unsatisfactory indication. For this purpose the electrical element necessary is merely a disc of bismuth as large as a shilling soldered to a corresponding one of copper, blackened and erected in the focus of the reflector, while the conductors pass from each disc to the poles of the galvanometer. With this arrangement the heat of a non-luminous ball at the distance of twelve feet will impel the needle near 180°, and if the connexions and reversals are properly made will keep it in continued revolution.

(439) We have seen (49) that the lightness and flexibility of gold-leaf have rendered that metal highly valuable to the electrician

in the construction of instruments for appreciating minute quantities of statical Electricity. The same material, with the addition of a magnet, may be arranged so as to form probably one of the most delicate tests possible, of the existence and direction of a weak *galvanic* current. A slip of gold leaf is retained in the axis of a glass tube by a metallic forceps at each end, and a strong horse-shoe magnet is fixed with its poles on either side of the middle of the tube; on causing the electrical current to pass down the gold leaf it will be attracted or repelled, laterally by the poles of the magnet, according as the current is ascending or descending. (*Cumming's Manual of Electro-dynamics.*)

(440) Mr. Sturgeon also describes (*Lectures on Galvanism*, p. 80) an instrument in which a single gold leaf is employed, but instead of a magnet a dry electric pile is used: "A glass phial has its neck cut off and is perforated on its two opposite sides, for the introduction of two horizontal wires. These wires are formed into screws and work in box-wood necks which are firmly cemented to the bottle, with their centres directly over the perforations. Through the centre of a wooden cap, cemented to the top of the bottle, passes a brass wire tapped at its upper extremity for the reception of a metallic plate, and from its lower extremity hangs a very narrow slip of gold leaf pointed at its lower end, which reaches just as low as the inner balls of the horizontal wires. The bottle stands upon and is cemented to a boxwood pedestal. Upon two glass pillars fixed to a wooden base is placed horizontally, a dry electric pile, consisting of about one hundred pairs, or rather single pieces of zinc with bright and dull surfaces. The poles of this pile are connected with the two horizontal wires by thin copper wires." The sensibility of this instrument Mr. Sturgeon states to be very great. A zinc plate about the size of a sixpence being attached to the upper end of the axial wire, on pressing upon it a similar sized copper plate, the pendant leaf leans towards the *negative* ball, and when the copper is suddenly lifted up, the leaf will strike; when the plates are reversed the leaf leans towards, and strikes the *positive* ball.

(441) Mr. Iremonger describes (*Proceedings of the London Electrical Society,*) an ingenious galvanometer on hydrostatic principles. "A small bar magnet is attached to the bottom of an areometer: this apparatus being so weighted that the ball may float just below the surface of pure water. Over the proof glass, containing the said areometer, is passed a De la Rive's ring placed rather below the level of the lower pole of the magnet. Now, on passing a voltaic current through the ring, the magnet and areometer are forced downwards: but at the same time I accompany this motion by a corresponding

movement of the ring, by which means the descent of the floating apparatus is continued till the electro-magnetic forces are in equilibrium with the upward pressure of the liquid. Now, the pressure of liquids being simply as their height, the different degrees of any *equally* divided scale attached to this instrument, will be of *equal* value—no slight advantage. The delicacy of the instrument will depend on several circumstances, such as the size of the stem of the areometer, the strength of the magnet, and also on the length of wire and number of turns in the ring." Mr. Iremonger gives a detailed account of the method of constructing this instrument, for which, as it could not be well understood without a drawing, the reader is referred to his original paper, in the *Proceedings of the Electrical Society*.

(442) *Physiological Effects of Galvanism.*—The action of galvanic Electricity on the living animal, is the same as that of the common electric current, account being taken of the *intensity* of the one, and the *duration* of the other. When any part of the body is caused to form part of the circuit of the voltaic pile, a distinct shock resembling that of a large electrical battery weakly charged, is experienced every time the connection with the extremities is made; and besides this, if the pile be a large one, a continued aching pain is frequently felt as long as the current is passing through the body, and if the slightest excoriation or cut happen to be in the path of the currrent, the pain is very severe. The intensity of galvanic Electricity is so low that it requires good conductors for its transmission; unless, therefore, the skin be previously moistened, it will not force its way through the badly conducting cuticle, or outer skin. The most effectual mode of receiving the whole force of the battery, is to wet both hands with water, or with a solution of common salt, and to grasp a silver spoon in each, and then to make the connection between the poles of the battery. Another method is to plunge both hands into two separate vessels of water, into which the extremities of the wires from the battery have been immersed. Volta has remarked, that the pain is of a sharper kind on those sensible parts of the body included in the circuit, which are on the negative side of the pile; this is particularly remarkable with the water-battery, and the same has been noticed with regard to the pungency of the common electrical spark.

(443) It does not require a voltaic pile to exhibit the effects of galvanic Electricity on the animal, whether living or dead. The simple application of a piece of zinc and one of silver to the tongue and lips, frequently gives rise, at the moment of the contact of the metals, to the perception of a luminous flash; but the most certain

way of obtaining this result, is to press a piece of silver as high as possible between the upper lip and the gums, and to insert a silver probe into the nostrils, while at the same time a piece of zinc is laid upon the tongue, and then to bring the two metals into contact. Another mode is to introduce some tin foil within the eyelid, so as to cover part of the globe of the eye, and place a silver spoon in the mouth, which must then be made to communicate with the tin foil, by a wire of sufficient length; or, conversely, the foil may be placed on the tongue, and the rounded end of a silver probe applied to the inner corner of the eye, and the contact established as before. This phenomenon is evidently produced by an impression communicated to the retina or optic nerve, and is analogous to the effect of a blow on the eye, which is well known to occasion the sensation of a bright luminous coruscation, totally independent of the actual presence of light. In the like manner the flash from galvanism is felt, whether the eyes are open or closed, or whether the experiment is made in day light or in the dark. If the pupil of the eye is watched by another person when this effect is produced, it will be seen to contract at the moment the metals are brought into contact; a flash is also perceived the moment the metals are separated from each other. When different metals are applied to different parts of the tongue, and made to touch each other, a peculiar taste is perceived: in order that this experiment should succeed, the tongue must be moist; the effect is materially diminished if it be previously wiped, and cannot be produced at all if the surface be quite dry. The quality of the metal laid upon the tongue influences the kind of taste which is communicated; the more oxidable metal giving rise to an acid, and the less oxidable metal to a distinct alkaline taste. Similar differences have been observed by Berzelius, with regard to the sensations excited in the tongue, by common Electricity directed in a stream upon that organ from a pointed conductor; the taste of positive Electricity being acid, and that of negative Electricity caustic and alkaline.

(444) If the hind legs of a frog be placed upon a glass plate, and the crural nerve dissected out of one, made to communicate with the other, it will be found on making occasional contacts with the remaining crural nerve, that the limbs of the animal will be agitated at each contact. Aldini, the nephew of the original discoverer of galvanism, produced very powerful muscular contraction, by bringing a part of a warm-blooded and of a cold-blooded animal into contact with each other, as the nerve and muscle of a frog, with the bloody flesh of the neck of a newly decapitated ox, and also by bringing the nerve of one animal into contact with the muscle of another.

(445) If a crown piece be laid upon a piece of zinc of larger size,

and a living leech be placed upon the silver coin, it suffers no inconvenience as long as it remains in contact with the silver only, but the moment it has stretched itself out and touched the zinc, it suddenly recoils, as if from a violent shock. An earth worm exhibits the same kind of sensitiveness. The convulsive movements excited in the muscles of animals after death, by a powerful galvanic battery, are extremely striking if the power is applied before the muscles have lost their contractility. Thus, if two wires connected with the poles of a battery of a hundred pairs of plates are inserted into the ears of an ox or sheep, when the head is removed from the body of the animal recently killed, very strong actions will be excited in the muscles of the face every time the circuit is completed. The convulsions are so general as often to induce a belief that the animal has been restored to life, and that he is enduring the most cruel sufferings. The eyes are seen to open and shut spontaneously; they roll in their sockets as if again endued with vision; the pupils are at the same time widely dilated; the nostrils vibrate as in the act of smelling; and the movements of mastication are imitated by the jaws. The struggles of the limbs of a horse galvanised soon after it has been killed, are so powerful as to require the strength of several persons to restrain them.

(446) The following account of some experiments made by Dr. Ure on the body of a recently-executed criminal, will serve to convey a tolerably accurate idea of the wonderful physiological effects of this agent, and will be impressive from their conveying the most terrific expressions of human passion and human agony:—

"The subject of these experiments was a middle-sized, athletic, and extremely muscular man, about thirty years of age. He was suspended from the gallows nearly an hour, and made no convulsive struggle after he dropped; while a thief, who was executed along with him, was violently agitated for a long time. He was brought into the anatomical theatre of our university about ten minutes after he was cut down. His face had a perfectly natural aspect, being neither livid, nor tumefied, and there was no dislocation of the neck.

"Dr. Jeffray, the distinguished professor of anatomy, having on the preceding day requested me to perform the galvanic experiments, I sent to his theatre the next morning with this view, my minor voltaic battery, consisting of two hundred and seventy pairs of four-inch plates, with wires of communication, and pointed metallic rods with insulating handles, for the more commodious application of the electric power. About five minutes before the police-officers arrived with the body, the battery was charged with dilute nitro-sulphuric acid, which speedily brought it into a state of intense action. The

dissections were skilfully executed by Mr. Marshall, under the superintendence of the professor.

"*Experiment* 1.—A large incision was made in the nape of the neck just below the occiput; the posterior half of the atlas vertebra was then removed by bone forceps; when the spinal marrow was brought into view, a profuse flow of fluid blood gushed from the wound, inundating the floor. A considerable incision was at the same time made in the left hip, through the great gluteal muscle, so as to bring the sciatic nerve into sight, and a small cut was made in the heel; from neither of these did any blood flow. The pointed rod connected with one end of the battery was now placed in contact with the spinal marrow, while the other rod was applied to the sciatic nerve; every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most powerfully convulsed. On removing the second rod from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension.

"*Experiment* 2.—The left phrenic nerve was now laid bare at the outer edge of the *sternothyroideus* muscle, from three to four inches above the clavicle; the cutaneous incision having been made by the side of the sterno-cleido-mastoideus. Since this nerve is distributed to the diaphragm, and since it communicates with the heart through the eighth pair, it was expected by transmitting the galvanic current along it, that the respiratory process would be renewed. Accordingly a small incision having been made under the cartilage of the seventh rib, the point of the one insulating rod was brought into contact with the great head of the diaphragm, while the other point was applied to the phrenic nerve in the neck. This muscle, the main agent of respiration, was immediately contracted, but with less force than was expected. Satisfied from ample experience on the living body, that more powerful effects can be produced by galvanic excitation, by leaving the extreme communicating rod in close contact with the parts to be operated on, while the electric chain or circuit is completed by running the end of the wires along the top of the plates in the last trough of either pole, the other wire being steadily immersed in the last cell of the opposite pole, I had immediate recourse to this method. The success of it was truly wonderful; full, nay, laborious breathing, instantly commenced, the chest heaved and fell, the belly protruded, and again collapsed with the relaxing and retiring diaphragm. This process was continued without interruption as long as I continued the electric discharges. In the judgment of many scientific friends who witnessed the scene, this respi-

ratory experiment was perhaps the most striking ever made with philosophical apparatus.

"Let it also be remembered, that for full half an hour before this period, the body had been well nigh drained of its blood, and the spinal marrow severely lacerated. No pulsation could be perceived, meanwhile at the heart or wrist; but it may be supposed that but for the evacuation of blood, the essential stimulus of that organ, this phenomenon might also have occurred.

"*Experiment* 3.—The super-orbital nerve was laid bare in the forehead, as it issues through the supra-ciliary foramen in the eye-brow; the one conducting rod being applied to it, and the other to the heels, most extraordinary grimaces were exhibited every time the electric discharges were made, by running the wire in my hand over the edges of the plates in the last trough, from the two hundred and twentieth to the two hundred and seventieth pair, thus fifty shocks, each greater than the preceding ones, were given in two seconds. Every muscle of his countenance was simultaneously thrown into fearful action; rage, horror, despair, and anguish, and ghastly smiles united their hideous expression in the murderer's face, surpassing far the wildest representations of a Fuseli or a Kean. At this period several of the spectators were obliged to leave the room from terror or sickness, and one gentleman fainted.

"*Experiment* 4.—The last galvanic experiment consisted in transmitting the electric power from the spinal marrow to the ulnar nerve, as it passes by the internal condyle at the elbow; the fingers now moved nimbly, like those of a violin performer: an assistant, who tried to close the fist, found the hand to open forcibly in spite of his efforts. When one rod was applied to a slight incision on the top of the forefinger, the first being previously clenched, the fingers extended instantly, and from the convulsive agitation of the arm, he seemed to point to the different spectators, some of whom thought he had come to life. About an hour was spent in these operations."

(447) In these experiments the positive wire was always applied to the *nerve*, and the negative to the *muscles*; that this is important, will appear from the following facts:—

Let the posterior nerve of a frog be prepared for electrization, and let it remain till its voltaic susceptibility is considerably blunted, the crural nerves being connected with a detached portion of the spine; plunge the limbs into one glass full of water, and the crural nerves, &c. into another glass; then take a rod of zinc in one hand, and a silver tea-spoon in the other, plunge the former into the water of the limbs' glass, and the latter into the water of the nerves' glass, without touching the frog itself, and gently strike the dry parts of

the metals together; feeble convulsive movements or mere twitching of the fibres will be perceived at each contact; reverse now the position of the metal rods, and on renewing the contact between them, very lively convulsions will take place, and if the limbs are skilfully disposed in a narrow conical glass, they will probably spring out to some distance. Or, let an assistant seize in his moistened left hand the spine and nervous cords of the prepared frog, and in his right a silver rod, and let another person lay hold of one of the limbs with his right hand, and a zinc rod in the moist fingers of the left; on making the contact, feeble convulsive twitching will be perceived as before; now let the metals be reversed; on renewing the contact, lively movements will take place, which become very conspicuous; if one limb be held nearly horizontal, while the other hangs freely down, at each touch of the voltaic pair, the drooping limb will start up and strike the hand of the experimenter.

Hence, for the purposes of resuscitating the dormant irritability of the nerves, as Dr. Ure remarks, or the contractility of their subordinate muscles, the positive pole must be applied to the former and the negative to the latter.

(448) Some interesting researches, on the relation between voltaic Electricity and the Phenomena of Life, were published in the Philosophical Transactions by Dr. Wilson Philip.

In his earlier researches, he endeavoured to prove that the circulation of the blood, and the action of the involuntary muscles, are independent of the nervous influence. In a paper, read in January, 1816, he showed the immediate dependence of the secretory function on the nervous influence. The eighth pair of nerves distributed to the stomach, and subservient to digestion, were divided by incisions in the necks of several rabbits; after the operation, the parsley which they ate remained without alteration in their stomachs, and the animals, after evincing much difficulty in breathing, appeared to die of suffocation. But when in other rabbits similarly treated, the galvanic power was distributed along the nerve below its section, to a disc of silver placed closely in contact with the skin of the animal opposite to its stomach, no difficulty of breathing occurred. The voltaic action being kept up for twenty-six hours, the rabbits were then killed, and the parsley was found in as perfectly digested a state as that in healthy rabbits fed at the same time; and their stomachs evolved the smell peculiar to that of rabbits during digestion. These experiments were several times repeated with similar results.

Thus a remarkable analogy is shown to exist between the galvanic energy and the nervous influence, the former of which may be made

to supply the place of the latter, so that while under it, the stomach, otherwise inactive, digests food as usual.

(449) Dr. Philip was next led to try galvanism as a remedy in asthma. By transmitting its influence from the nape of the neck to the pit of the stomach, he gave decided relief in every one of twenty-two cases, of which four were in private practice, and eighteen in the Worcester infirmary. The power employed varied from ten to twenty-five pairs.

(450) These results of Dr. Philip have since been confirmed by Dr. Clarke Abel, of Brighton (Journ. Sc. ix.): this gentleman employed, in one of his repetitions of the experiments, a comparatively small, and in the other a considerable, power. In the former, although the galvanism was not of sufficient power to occasion evident digestion of the food, yet the efforts to vomit and the difficulty of breathing, (constant effects of dividing the eighth pair of nerves,) were prevented by it. The symptoms recurred when it was discontinued, but vanished on its re-application. "The respiration of the animal," he observes, "continued quite free during the experiment, except when the disengagement of the nerves from the tin foil, rendered a short suspension of the galvanism necessary, during their re-adjustment. The non-galvanized rabbit wheezed audibly, and made frequent attempts to vomit. In the latter experiment, in which greater power of galvanism was employed, digestion went on, as in Dr. Philip's experiments."

(451) It had been suggested by an eminent French physiologist, M. Gallois, that the motion of the heart depends entirely upon the spinal marrow, and immediately ceases when the spinal marrow is removed or destroyed. But Dr. Philip rendered rabbits insensible by a blow on the occiput, the spinal marrow and brain were then removed and the respiration kept up by artificial means; the motion of the heart and circulation were carried on as usual. When spirit of wine or opium was applied to the spinal marrow or brain, the rate of circulation was accelerated. These experiments appear to confute the notion of M. Gallois.

(452) The general inferences deduced by Dr. Philip from his numerous experiments are, that Voltaic Electricity is capable of effecting the formation of the secreted fluids when applied to the blood, in the same way in which the nervous influence is applied to it; and that it is capable of occasioning an evolution of caloric from arterial blood, when the lungs are deprived of the nervous influence, by which their function is impeded, and even destroyed; when digestion is interrupted by withdrawing this influence from the stomach,

these two vital functions are renewed by exposing them to the influence of a galvanic trough. "Hence," says he, "galvanism seems capable of performing all the functions of the nervous influence, in the economy: but obviously, *it cannot excite the functions of animal life, unless when acting on parts endowed with the vital principle.*"

Application of Galvanic Electricity to the treatment of diseases.

(453) The following observations on this subject occur in the *Cyclopædia of Practical Medicine*, from the pen of Dr. Apjohn:—

"There are several diseases incident to the human frame, in which the application of galvanism by the hand of a skilful physician, may be, and indeed has been, attended with happy results. In asphyxia, for instance, whether proceeding from strangulation, drowning, narcotic poisons, the inhalation of noxious gases, or simple concussion of the cerebral system, it has been applied with success. In all these cases, the interrupted current—that is, a succession of shocks—should be resorted to; the battery should be pretty powerful, and care should be taken that the Electricity be as much as possible confined to the nerves, and that it be sent along them in the direction of their ramifications. M. Goudret was the first who proposed galvanism in cases of asphyxia produced by concussion of the brain; he experimented on rabbits, which were to all appearance killed by a few violent blows inflicted upon the back of the head, and succeeded in recovering them perfectly by a succession of shocks continued for half an hour from a battery of thirty couples, and transmitted between the eyes, nose, and *meatus auditorius externus* on the one hand, and different parts of the spine of the animal on the other. The same experiments have been repeated by Majendie, Apjohn, and others with perfect success, and the former states that he has recovered rabbits asphyxiated by submersion in water for more than a quarter of an hour.

In paralytic affections also, which are of a purely functional character, or which do not depend upon organic diseases of the nervous system, or pressure exercised on any part of it, the agency of the pile can be rationally resorted to by the medical practitioner. Under this head may be ranged general or local paralysis, arising from exposure to cold, palsy of the wrists from the absorption of lead, and many varieties of deafness and amaurosis. In all these cases, as the nerves are to be stimulated to increased action, an interrupted current must be employed. In cases of deafness, to submit the auditory nerve to galvanic action, it is sufficient to introduce a wire connected with one of the poles of a battery into the affected ear,

and the other wire into the opposite ear, the circuit then being rapidly broken and completed by an assistant.

(454) In *amaurosis*, the galvanic shock may be transmitted at pleasure through the ball of the eye, so as to traverse the retina, or be confined to those twigs of the first branch of the fifth pair of nerves, which ramify on the forehead above the orbit, and upon the state of which alone Majendie has shown that gutta serena often depends. In *aphonia*, the circuit may be completed through the organs chiefly concerned in the production of the voice, by placing a shilling upon the tongue and touching it with the negative wire of a battery whose other pole is alternately brought into connexion with, and separated from, different parts of the external larynx.

(455) The following case of a cure of an *epileptic* patient by galvanic treatment is related by Dr. Pearson (*Revue Médicale*, vol. iii. p. 333). The cuticle having been removed by a blister from the back of the neck and inner side of one knee, those parts were covered with bits of moistened sponge, upon which slips of linen were laid, and over all, discs of silver and copper, the former metal being applied to the neck, the latter to the knee. The discs were then connected by a copper wire and enclosed in a pouch composed of chamois leather, so as to be insulated from adjacent parts. This apparatus having been applied for six months, the case was cured. It was found to continue in action for ten or twelve hours, after which it became necessary to clean the plates and renew the pledgets of sponge and linen.

(456) Galvanism, in the form of the continued current, has also been strongly recommended by Dr. Wilson Philip for the treatment of what he denominates *habitual asthma*. His method is to apply a disc of silver to the nape of the neck, and another to the epigastric region, and then press the positive wire of a galvanic trough, consisting of from 8 to 16 pairs of 4 inch plates charged with very dilute muriatic acid, against the former, and the negative wire against the latter: relief usually occurs in from five to fifteen minutes.

Another application of the galvanic pile is to the coagulating the blood within an aneurismal tumour; this is founded on the discovery of Brande, that "when the wires attached to the extremities of the trough are introduced into any animal fluid containing albumen, the latter principle separates at the positive pole in a coagulated state." A case in which a perfect cure of an aneurism of the temporal artery was effected by galvanism, is related by M. Petrequin (*Comptes Rendus*, Nov. 3, 1845). Two needles were thrust into the tumour, and the power employed was gradually augmented up to 50 pairs. At the end of 12 minutes the throbbing had entirely ceased, and the

aneurism with isochronous pulsations was replaced by a solid and indurated tumour.

(457) Galvanism has also been applied by M. Pravaz (*Revue Médicale*, December 1830,) as an *escharotic* to wounds caused by the bites of rabid animals. He details several cases in which this practice was successful, in one of which the cauterization was not resorted to until 54 hours after the reception of the bite. The battery he used was of low power, consisting of only two troughs, containing between them but fifty pairs of electromotors. The eschar was usually detached on the eleventh day, and the cicatrization completed on the seventeenth.

(458) A very curious application of the pile was suggested by Prevost and Dumas (*Journal de Physiologie*, tom. iii. p. 207). Reflecting on its powers of decomposition, it occurred to them that it might be successfully employed for breaking down the materials which compose urinary calculi, and that thus the necessity for one of the most formidable of surgical operations would be obviated. Their idea in fact was to introduce into the bladder a *canula* containing two platina wires carefully insulated from each other, and whose internal ends should be brought in contact with the stone, while their external extremities were put in connexion with the poles of a powerful battery. Upon the established principles of electro-chemistry, they expected that it would be resolved into its acids and bases, the former assembling at the positive, the latter at the negative pole, and that in this way its gradual disintegration would be effected. A preliminary experiment made upon a fusible calculus, placed in a basin of water, and a second upon a stone of the same kind, introduced into the bladder of a dog previously injected with tepid water gave encouraging results. The former submitted for 8 hours to the action of a battery composed of 120 pairs, was reduced from 92 to 80 grains, and in 8 additional hours was so disintegrated as to break into small crystalline fragments upon the application of the slightest pressure. The latter underwent similar changes, and they found that no irritating effect whatever was produced upon the bladder, however powerful the battery which they employed. The manipulations are however exceedingly difficult, as may easily be imagined, and the proposal has not hitherto been acted on.

(459) For the medical application of voltaic Electricity, the old Cruikshank trough may be employed; the exciting agent being dilute sulphuric acid. The mode of application may differ in different cases; when it is to be applied on the surface, the current may be transmitted through the medium of *sponges*; or, what is perhaps

more convenient, by means of saddles of thin sheet copper covered with thick flannel, and saturated with brine, the surface of the skin being also well moistened with salt and water. It is sometimes, however, desirable to act on parts deeply seated below the surface; in such cases, the following method of M. Sarlandière may be adopted: Needles of steel or platinum are introduced, as in the process of acupuncturation, the needles being connected respectively with the two opposite ends or poles of the battery. Becquerel considers this to be the most efficacious mode of applying Electricity, since it permits the operator to act directly on the diseased part. Several ingenious "electro-voltaic" batteries for physiological purposes have recently been invented. Pulvermacher's modification of the pile consists of a chain formed of a series of gilded copper and zinc wires wound closely together round pieces of porous wood; to excite it, the wood is immersed in vinegar, a sufficient quantity of which is absorbed to act on the zinc, the elements of the chain are connected by small metallic hooks; 100 links give a pretty strong shock. Stringfellow's patent pocket battery is an elegant, and, for its size, a surprisingly powerful arrangement. Each element consists of a strip of zinc about 2½ inches long, round which is wound, as closely as possible, but not in absolute metallic contact, a coil of flattened copper wire forming 30 convolutions. A series of six of these elements when excited with weak acetic acid gives distinct shocks, and decomposes unacidulated water. A set of 22 gives a brilliant spark between graphite points, decomposes unacidulated water briskly, and gives pretty smart shocks; and the power is scarcely impaired, after half an hour's action; the battery is charged by drawing a small piece of sponge, moistened with distilled vinegar, (one part acetic acid to seven parts of water) several times down the centre on both sides of each fold; it is then replaced in its case, not longer than a common card-case, and the current applied to any part of the body by means of two small metallic discs attached to either pole of the battery by elastic cords.

(460) It was first noticed by Marianini that the force of the shock differs considerably according as the current goes in one direction or another; thus, if a person grasp two conductors connected with the poles of an extensive voltaic battery in vigorous action, he will experience a much more powerful muscular contraction in the arm which is in communication with the *negative*, than in that connected with the *positive* end; so also, if the current be passed down the arm from the shoulder to the hand, the latter being immersed in a basin of salt water, a powerful contraction is experienced;

if, however, the current be passed from the hand to the shoulder, the contractions are much less violent, and the difference is observed most strikingly in paralytic patients.

(461) The following explanation of these differences is offered by Marianini:—The action of Electricity on the muscles and nerves produces two distinct kinds of contractions; the first, which he calls *idiopathic*, is the result of the immediate action of the current on the muscles; and the second, which he calls *sympathetic*, arises from the action of Electricity on the nerves which preside over the motions of the muscles. Now, *idiopathic* contractions are necessarily produced in whatever direction the current of Electricity passes; but the occurrence of *sympathetic* contractions must be governed by the direction of the passing current —they can only take place when the Electricity is transmitted in the direction of the ramification of the nerves; the shocks then, experienced when the current is transmitted from the shoulder to the hand, are more powerful than those passed in the reverse direction, because in the former case the Electricity is transmitted in the direction of the ramifications of the nerves, and in the latter in the contrary direction. These facts, which the researches of Matteucci confirm and illustrate in a satisfactory manner, will serve as a valuable guide to the Electrician in his treatment of cases of paralysis by this form of Electricity.

(462) Majendie and Grapengresser have paid much attention to the curative effects of galvanism in *amaurosis* and *deafness*; the same observations, which we made above, respecting the care and anatomical knowledge requisite for treating such diseases by frictional Electricity, apply also here, and perhaps even with greater force. Majendie's usual plan was to employ acupuncturation, making the electrical current act directly on the nerves of the orbit of the eye; and in this way he accomplished some remarkable cures. Grapengresser proceeded in a different manner. He introduced into the nose a silver probe connected with the positive end of the battery, and touched the region of the frontal nerve, previously well moistened, with a wire connected with the negative end. In cases of deafness, he used two silver wire conductors, each bent at one end, exactly in the direction of the *meatus auditorius*, and terminating in a small knob exactly fitting the auditory canal, which was covered with linen and moistened. The current running through the nerves with great rapidity, is communicated to the auditory nerve, and generally occasions the sensation either of a loud noise or of a tinkling sound. A feeble power must be employed in these cases, and be continued for only a few minutes at a time; as a general rule, the operator should

in all cases commence with a weak battery, gradually increasing its strength as the case progresses: in cases of paralysis, the battery power required frequently rises to 100 pairs.

(463) The observation was made long since by Humboldt, that a a very weak galvanic power was capable of exercising a remarkable influence on the secretions from wounds; he found that when a simple arc was applied to a blistered surface, the part exposed to the most oxidable metal was more irritated than that to which the negative plate was applied. Dr. Golding Bird has made an ingenious application of this singular fact to the production of *puriginous* sores, in the place of the *issue* and *seton*. His plan is the following: By means of small blisters he raises the skin by effused serum, and having snipped it, he applies to the blister from which a permanent discharge is required a piece of zinc foil, and to the other a piece of silver, the two metals being connected by a wire, and covered with a common water dressing and oiled silk. On raising the zinc-plate after a few hours, the surface of the skin underneath will have assumed a white appearance, as if it had been rubbed with nitrate of silver: in forty-eight hours a decided *eschar* will appear, which, still keeping on the plates, will, at the end of a few days, begin to separate at the edges. The plates may then be removed; the surface where the silver was applied will be found to be completely healed. A common poultice may then be applied to the part, and a healthy granulating sore, with well-defined edges, freely discharging pus, will be left. During the whole process, if the patient complains of pain at all, it will always be referred to the silver plate, where, in fact, the blister is rapidly healing; and not the slightest complaint will be made of the zinc-plate, where the slough is as rapidly forming.

(464) Dr. Bird is of opinion, that in this method of forming a sore the *escharotic* action is that of the *chloride of zinc*, which is produced by the chlorine set free, by the galvanic action from the *chloride of sodium* constituting the saline ingredient of the fluid, effused on the surfaces of the blisters; and, in illustration of the truth of his theory, he instances the following experiment made by Dr. Babington: The doctor took two slices of muscular flesh, and placed one between two plates of glass, and the other between plates of copper and zinc, binding them together with wire. In the course of a few days, the weather being warm, the flesh between the glasses began to putrefy, and soon afterwards was full of maggots; while that between the metallic plates remained free from putrescency. A remarkable change had, however, occurred; for on taking off the plates the side opposite the zinc-plate was hard, as if it had been artificially dried; while that opposed to the copper had become

covered with a transparent substance resembling jelly; in fact, observes Dr. Bird, the result of the experiment evidently was, that the chloride of sodium existing in the flesh had been decomposed, the zinc had been acted upon, and a dry, hard compound of chloride of zinc and albumen formed on one side of the piece, whilst the soda set free on the other side had become converted into *albuminate of soda*, in the form of a gelatinous mass.

CHAPTER IX.

EFFECTS OF THE HYDRO-ELECTRIC CURRENT.

(CONTINUED.)

Chemical Phenomena.

(465) Before entering upon this interesting branch of our subject, it will be necessary that we describe the new terms introduced by Faraday, and state his reasons for adopting them. According to the views of this philosopher (*Experimental Researches*, 518, 524), electro-chemical decomposition is occasioned by an *internal corpuscular action*, exerted according to the direction of the electric current, and is due to a force either *superadded to, or giving a direction to, the ordinary chemical affinities* of the bodies present. He conceives the effects to arise from *forces* which are *internal*, relative to the matter under decomposition, and not *external*, as they might be considered if directly dependent upon the poles. He supposes that the effects are due to a modification, by the electric current, of the chemical affinity of the particles through, or by which, that current is passing, giving them the power of acting more forcibly in one direction than in another, and consequently making them travel by a series of successive decompositions and recompositions in opposite directions, and, finally, causing their expulsion or exclusion at the boundaries of the body under decomposition, in the direction of the current, *and that*, in larger or smaller quantities, according as the current is more or less powerful.

Fig. 190.

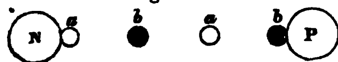
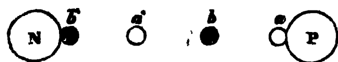


Fig. 191.



Thus, in Fig. 190, the particles *a a* could not be transferred, or travel from one pole N, towards the other P, unless they found particles of the opposite kind, *b b*, ready to pass in the opposite direction; for it is by virtue of their increased affinity for those particles, combined with their diminished affinity for such as are behind them in their course, that they are urged forward; and when any one particle *a*,

Fig. 191, arrives at the pole, it is excluded or set free, because the particle *b* of the opposite kind, with which it was the moment before in combination, has, under the super-inducing influence of the current, a greater attraction for the particle *a'*, which is before it in its course, than for the particle *a*, towards which its affinity has been weakened: *a* may be conceived to be expelled from the compound *a b*, by the superior attraction of *a'* for *b*, that superior attraction belonging to it in consequence of the relative position of *a'* *b* and *a*, to the direction of the axis of electric power superinduced by the current. The electric current is looked upon by Faraday as an *axis of power, having contrary forces, exactly equal in amount, in contrary directions.*

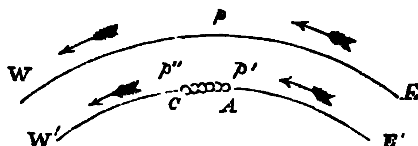
(466) According to Faraday's views (*Experimental Researches*, 518, 524), then, the determining force is *not* at the so called *poles* of the voltaic battery, but *within* the body under decomposition: to avoid, therefore, confusion and circumlocution, and for the sake of greater precision of expression, he framed the following new terms, some of which have since been generally adopted:—

What are called the *poles* of the voltaic battery are merely the surfaces or doors by which the Electricity enters into, or passes out of, the substance suffering decomposition; Faraday hence proposes for them the term *electrodes*, from ἤλεκτρον and ὁδὸς a way, meaning thereby, the substance, or surface, whether of air, water, metal, or any other substance, which serves to convey an electric current into, and from, the decomposing matter, and which bounds its extent in that direction.

(467) The surfaces at which the electric current enters and leaves a decomposing body, he calls the *anode* and the *cathode;* from ἄνα upwards, and ὁδὸς a way,—*the way which the sun rises;* and κατὰ downwards, and ὁδὸς a way,—*the way which the sun sets.* The idea being taken from the earth, the magnetism of which is supposed to be due to electric currents, passing round it in a constant direction from *east* to *west*,—if, therefore, the decomposing body be considered as placed so that the current passing through it shall be in the same direction, and parallel to that supposed to exist in the earth, then the surfaces at which the Electricity is passing into, and out of, the substance, would have an invariable reference, and exhibit constantly the same relations of powers. The *anode* is, therefore, that surface at which the electric current enters: it is the *negative* extremity of the decomposing body; is where oxygen, chlorine, acids, &c., are evolved; and is against or opposite the positive electrode. The *cathode* is that surface at which the current leaves the decomposing body, and is its *positive* extremity: the combustible bodies, metals, alkalies, and bases, are evolved there, and it is in contact with the

negative electrode. Thus, in Fig. 192, if we suppose a current of Electricity traversing a wire in the direction of the darts, and entering at E, then, on separating the wires at p, p' p'' would become its electrodes: p' would be the *anelectrode* or emitting electrode, and p'' the *cathelectrode*, or receiving electrode; E being the wire connected with the last *active* copper plate, and W the wire connected with the last *active* zinc plate of a battery; and if we suppose the chain of small circles to represent the fluid under decomposition, A will be its anode and C its cathode.

Fig. 192.



(468) Compounds directly decomposable by the electric current are called *electrolytes*, from ἤλεκτρον and λύω to set free,—to *electrolyze* a body is to decompose it electro-chemically: the elements of an electrolyte are termed *iöns*, from ἰὼν, participle of the verb εἶμι, to go; *anions* are the iöns which make their appearance at the anode, and were formerly termed the electro-negative elements of the compound, and *cations* are the iöns which make their appearance at the cathode, and were termed the electro-positive elements. Thus, chloride of lead is an *electrolyte*, and when *electrolyzed* evolves two *iöns*, chlorine and lead, the former being an *anion*, and the latter a *cation*: water is an electrolyte, evolving likewise two iöns, of which oxygen is the anion, and hydrogen the cation: muriatic acid is likewise electrolytical, boracic acid, on the other hand, is not.

(469) Mr. Daniell proposes further to distinguish the doors by which the current enters and departs, by the terms *zincode* and *platinode*, the former being the plate which occupies the position of the generating plate in the battery, and the latter of the conducting plate; when water is decomposed, therefore the last particle of oxygen gives up its charge to the zincode, and the last particle of hydrogen gives up its charge to the platinode, each passing off in its own elastic form.

(470) Fechner, a distinguished champion of the contact theory (323), assumes that the elements of an electrolyte are in opposite electrical conditions, as the result of their *contact*, the same process being carried on between them as between two *electromotors* when brought into contact: before, therefore, the separation of the elements can take place by the electric current, the attractive force of the positive pole on the negative particle must exceed the force by which it is united to the positive particle; a separation being thus effected, and the positive particle being repelled, it combines momentarily with the negative particle of the second link in the chain of electrolytes, which

is itself attracted towards the positive pole, but the overpowering action of which quickly again separates it, and thus the influence is regularly transmitted, through the entire stratum of the electrolyte lying between the poles. The same influence which is assumed to emanate from the positive, proceeds also from the negative pole, but it acts on the elements in the contrary direction. In this theory, electrolysis is maintained by the simultaneous and corresponding action of both poles, and the elements of the electrolyte are themselves, from their *contact*, exciters of Electricity.

(471) The chemical power of the voltaic pile was discovered and described by Messrs. Nicholson and Carlisle, in the year 1800. Water was the first substance decomposed. In 1806, Davy communicated to the Royal Society his celebrated lecture "on some chemical agencies of Electricity," and in 1807, he announced the grand discovery of the decomposition of the fixed alkalies. The years from 1831 to 1840 are marked in science by the publication of the masterly researches of Faraday, in which, much that was before unintelligible, has not only been explained and enlightened, but a new character has been stamped on electrical, as connected with chemical, science. Of these remarkable essays, it has been said, that in point of originality of talent and perspicuity, they rank among the first efforts of philosophy of the age, if indeed they do not surpass all others.

(472) When water and certain saline solutions are made part of the electric circuit, so that a current of Electricity may pass through them, they are decomposed, that is, they yield up their elements in obedience to certain laws. Water is resolved into oxygen and hydrogen gases, and the acid and alkaline matters of the neutral salts, which it holds in solution, are separated, *not* in an indiscriminate manner, but the oxygen and acids are always developed at the anode, and the hydrogen and alkaline bases are given off at the cathode. If pure water be submitted to the action of the current, it is decomposed with great difficulty, in consequence of its bad conducting power. A greatly increased conducting power is, however, given to it by the addition of salts, and particularly by sulphuric acid, though that compound is *not* itself capable of electrolysis. One essential condition of electrolysis is liquidity: and the current of a powerful battery will be completely stopped by a film of ice, not more than one-sixteenth of an inch in thickness.* To decompose acidulated water, it may be confined in a glass tube, sealed hermetically at one extremity, and made part of the electrical circuit by

* Faraday's Experimental Researches, 381, et seq.

means of gold or platinum wires, or arranged as in Fig. 193, the wires being about a quarter of an inch apart. When the tube is about half full of the mixed gases, if a spark from the electrophorus (Fig. 20) be passed between the wires, an explosion will take place; and if care be taken to prevent any escape, by the expansion, the tube will be re-filled with water, that fluid having been reproduced by the explosion. If two glass receiving tubes be employed, one over either electrode, gas will be collected in each; but that in the tube over the cathode will be rather more than double in volume that over the anode, the former being hydrogen and the latter oxygen. Now the hydrogen and oxygen gases are to each other in water exactly as two to one, by volume: and the reason they do not appear precisely in this proportion in the electrolysis of that fluid, is because oxygen is partially soluble. By referring to Fig. 191 it will be immediately seen how it is that there is no visible transfer of the oxygen and hydrogen: if the electrodes were several inches apart, there would be no appearance of decomposition between them; the oxygen *a*′, of the atom of water *a*′ *b*′, under the superinducing influence of the current, is transferred to the hydrogen *b* of the second atom of water *a b*: the oxygen of this second atom is in like manner transferred to the hydrogen of a third, and so on till the electrode P is arrived at, against which the oxygen of the last particle is evolved, having nothing to combine with.

Fig. 193.

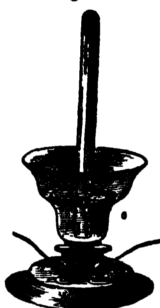
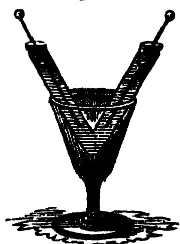


Fig. 194.

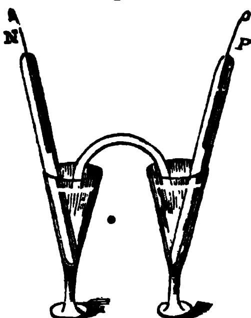


(473) Take a syphon-shaped tube, and placing its bent part in a wine glass for support (Fig. 194), or on any convenient stand, fill it with the blue infusion of red cabbage; then put a few crystals of some known salt, such as sulphate of soda, into the tube, and electrize the solution. In a short time the liquid nearest the cathode of the battery will become green, indicating the presence of free alkali; and the liquid nearest the anode will become red, showing that an acid is present: reverse the direction of the current, and the colours will also gradually be reversed. Thus, sulphate of soda is an electrolyte, the anion of which is sulphuric acid and the cation soda; and in all salts decomposable by the voltaic current, the acid passes to the anode and the base to the cathode.

(474) If two glasses be taken, both being filled with the blue infusion, holding in solution sulphate of soda, and an inverted glass tube, in which two platinum wires are sealed, be immersed in each,

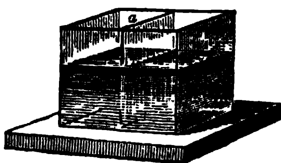
as shown in Fig. 195, and the two glasses connected together by a glass syphon filled with the liquid; on electrizing the solution, it will be found that, notwithstanding they are in separate vessels, the blue liquor will, as before, be turned red and green; and if the experiment be continued sufficiently long, the alkali of the salt will be found to have passed from P to N, and the acid from N to P, the acid and alkali appearing to traverse the syphon in opposite directions. It was hence inferred, that *under the influence of electrical attraction, the usual chemical affinities are suspended;* but the same explanation which accounted for the phenomenon of the decomposition of water, will serve here: a line of particles of sulphate of soda extend from one electrode to the other; and it is by a series of decompositions and recompositions that the effect is produced.

Fig 195.



(475) In various experiments of decomposition, the little form of apparatus of which Fig. 196 is a sketch, will be found exceedingly useful. It is a cell of plate glass, made by cementing five pieces together with transparent varnish, and supporting them upon a wooden foot, in which they are fastened. The cell is about five or six inches long, and an inch broad, and may be divided into two parts by the insertion of the temporary diaphragm *a*, which is a small frame of cane with muslin stretched over it. When this is in its place, a separate electrode may be introduced on each side of it; they may most conveniently consist of two pieces of thin platinum foil, about four inches long and half an inch broad.

Fig. 196.



To show the evolution of chlorine at the anode or positive pole, fill the glass cell with weak salt and water, acidulated with muriatic acid, and coloured blue by a few drops of the sulphuric solution of indigo; then introduce the electrodes. In a few minutes the *anodic* division will be found to lose colour, and will finally become colourless, owing to the separation of chlorine, which by its bleaching powers destroys the blue of the indigo.

The presence of uncombined iodine may be demonstrated, by filling the cell with a weak solution of *starch*, to which a little common salt and iodide of potassium have been added; then, on passing the electric current through the liquid, the iodine will show itself at the anode by

a beautiful blue colour, it being the property of this singular substance to strike a fine deep blue colour with starch.

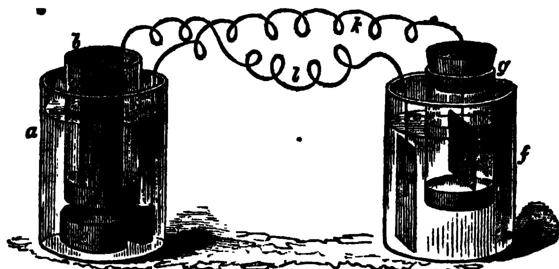
(476) Fill the cell with a solution of salt to which a few drops of yellow prussiate of potash have been added; introduce into each division a plate of iron as an electrode; the production of a deep blue colour in the anodic division while the liquid in the cathodic compartment remains colourless, will prove the oxidation and solution of iron at the anode, and the absence of all action at the cathode. In the like manner, pieces of silver and copper, both of which, under ordinary circumstances, are readily attacked by dilute nitric acid, may be made to resist the oxidizing power of that acid by making them the *cathelectrodes* of a battery. The experiment with copper may be made thus: immerse a strip of the metal for a few minutes in the acid; then remove it, and add a slight excess of ammonia; the production of a fine blue colour will announce the presence of copper in solution; now connect the strip of copper metallically with a similar strip of zinc, and immerse the pair in the acid; no blue colour will follow the introduction of ammonia into the acid as before, showing the protecting action of the zinc, the more oxidizable metal. This principle has received an important practical application, in the manufacture of which is called galvanized iron.

(477) The electro-reduction of the alkaline metals originally accomplished by Davy, with a battery of 100 pairs of six-inch copper and zinc plates, may be effected with a series of eight or ten cells of the nitric acid arrangement in the following manner: scoop out a cavity in a piece of pure moistened caustic potash or soda, and fill it with mercury: lay the alkali on a strip of platinum foil connected with the positive pole of the battery, and introduce into the mercury a platinum wire in contact with the negative pole, an amalgam of mercury and potassium or sodium will speedily be formed. In like manner, the ammoniacal amalgam may be formed by pouring a little mercury into a hole scooped in a lump of sal ammoniac and connecting the mercury with the negative, and the moistened sal ammoniac with the positive pole. This is a very striking experiment, the globule of mercury gradually increasing in size until it extends far beyond the cavity which first contained it, and the amalgam is produced more readily and copiously, if the mercury be previously combined with a small quantity of potassium or sodium.

(478) By means of the little apparatus shown in Fig. 197, Golding Bird (*Phil. Trans.* 1837) (*Nat. Philosophy*, p. 372,) obtained amalgams of potassium, sodium, and ammonium, with the feeble current from a single Daniell's pair.

A glass cylinder, *d*, 1·5 inch in diameter and 4 inches in length, is

Fig. 197.



closed at one end by means of a plug of plaster of Paris 0·7 inch in thickness; the cylinder is fixed by means of corks. Inside *c*, a cylindrical glass *a*, about eight inches deep and two inches in diameter; a piece of copper *c*, six inches long and three inches wide, having a copper conducting wire *k* soldered to it, is loosely coiled up and placed in the small cylinder with the plaster bottom; a piece of sheet zinc *e* of equal size is also loosely coiled up and placed in the larger external cylinder, being furnished, like the copper plate, with a conducting wire *l*. The larger cylindrical glass being then nearly filled with weak brine, and the smaller with a saturated solution of sulphate of copper, the two fluids being prevented from mixing by the plaster of Paris diaphragm, the apparatus is complete, and will continue to give a continuous current of Electricity for some weeks, provided care be taken that the fluids in the two cylinders are maintained at the same level. The decomposing apparatus is the counterpart of the battery itself. It consists of two glass cylinders, one within the other, the smaller one *g* having a bottom of plaster of Paris fixed into it; this smaller tube is about half an inch wide and three inches long, and is intended to hold mercury and the metallic solution submitted to experiment; the external tube *f* in which it is immersed being filled with a weak solution of common salt. In the latter, a slip of amalgamated zinc *i* is immersed for the positive electrode soldered to the wire coming from the positive plate of the battery; whilst for the negative electrode a slip of platinum foil *h*, fixed to the wire from the zinc plate of the battery, passes through a cork fixed in the mouth of the smaller tube, and dips into the metallic solution which it contains. In about eight or ten hours the mercury becomes swollen to double its former bulk, and when quickly poured into distilled water evolves hydrogen gas, and the water becomes alkaline. The ammonium amalgam was most easily obtained; it had a buttery consistence, and when immersed in water, slowly gave off hydrogen and yielded solution of ammonia. Bird found that the spongy ammoniacal amalgam, though it cannot be kept immersed in water even for a few instants without

the formation of ammonia, could nevertheless be preserved for weeks without change, as long as it was connected with the negative pole of the battery; with the same apparatus Dr. Bird reduced the metals from solutions of chloride or nitrate of *iron, copper, tin, zinc, bismuth, antimony, lead, and silver. Bismuth, lead, and silver* were beautifully crystalline; the latter of dazzling whiteness, and usually under the form of needles. He also obtained *silicon*, from a solution of chloride of silicon in alcohol.

Aluminium and *silicium* have recently been obtained by weak electric actions by Mr. Goze (*Phil. Mag.* March 1854;) the former was reduced from the chloride, by placing a dilute solution of the salt into a jar and immersing in the liquid a porous earthenware pot containing dilute sulphuric acid; a plate of amalgamated zinc was plunged into the acid, and a corresponding plate of copper into the chloride, the plates being connected by an arc of copper wire. After some hours the copper plate became covered with a lead-coloured deposit of aluminium, which when burnished, possessed the same degree of whiteness as platinum, and did not appear to tarnish readily by immersion in cold water, or in the atmosphere, but was acted upon by dilute sulphuric and nitric acids. *Silicium* was reduced from a solution of monosilicate of potash, prepared by fusing one part of silica, with $2\frac{1}{4}$ parts of carbonate of potash; the same voltaic arrangement was adopted as before, except that a small pair of Smee's batteries was interposed in the circuit; with a very slow and feeble action of the battery the colour of the deposited metal was much whiter than that of aluminium, closely approximating to that of silver.

(479) The following classification of the elementary substances by *Berzelius*, though not altogether derived from experiment, and therefore subject to correction and modification, is useful as indicating the electrical tendencies of a large number of bodies. In the list of negative substances, each element is to be considered as negative to all *below* and positive to all *above* it in the list, and the same applies to the list of positive substances. The elements are, therefore, negative and positive only in relation to each other. Thus, supposing a compound of oxygen and chlorine to be electrolyzed, the oxygen would go to the positive and the chlorine to the negative electrode; but if the compound were composed of chlorine and phosphorus, then the chlorine would go to the positive and the phosphorus to the negative electrode.—

I. ELECTRO-NEGATIVE ELEMENTS.

1. Oxygen.	4. Chlorine.
2. Sulphur.	5. Iodine.
3. Nitrogen.	6. Fluorine.

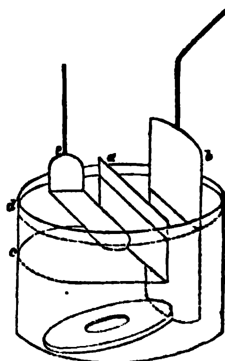
7. Phosphorus.
8. Selenium.
9. Arsenic.
10. Chromium.
11. Molybdenum.
12. Tungsten.
13. Boron.
14. Carbon.
15. Antimony.
16. Tellurium.
17. Columbium.
18. Titanium.
19. Silicon.
20. Osmium.
21. Hydrogen.

II. ELECTRO-POSITIVE BODIES.

1. Potassium.
2. Sodium.
3. Lithium.
4. Barium.
5. Strontium.
6. Calcium.
7. Magnesium.
8. Glucinum.
9. Yttrium.
10. Aluminium.
11. Zirconium.
12. Manganese.
13. Zinc.
14. Cadmium.
15. Iron.
16. Nickel.
17. Cobalt.
18. Cerium.
19. Lead.
20. Tin.
21. Bismuth.
22. Uranium.
23. Copper.
24. Silver.
25. Mercury.
26. Palladium.
27. Platinum.
28. Rhodium.
29. Iridium.
30. Gold.

(480) A substance cannot be transferred in the electric current beyond the point where it ceases to find particles with which it can combine; and it cannot be too strongly impressed, that electro-chemical decomposition does not depend upon any direct attraction or repulsion exerted by the metallic terminations either of the voltaic battery, or of the ordinary electrical machine. The beautiful experiments of Faraday, in which *air* was shown to act as a pole, have been quoted (213); in the following equally beautiful experiments (*Faraday's Exp. Researches*, 494), the decomposition of sulphate of magnesia against a surface of water, is most satisfactorily shown.

Fig. 198.



(481) A glass basin, four inches in diameter, and four inches deep, had a division of mica, *a*, Fig. 198, fixed across the upper part, so as to descend one inch and a half below the

edge, and to be perfectly water-tight at the sides. A plate of platinum, *b*, three inches wide, was put into the basin on one side of the division *a*, and retained there by a glass block below, so that any gas produced by it in a future stage of the experiment, should not ascend beyond the mica, and cause currents in the liquid on that side. A strong solution of sulphate of magnesia was carefully poured without splashing into the basin until it rose a little above the lower edge of the mica division *a*, great care being taken that the glass or mica, on the unoccupied or *c* side of the division in the figure, should not be moistened by agitation of the solution above the level to which it rose. A thin piece of clean cork, well wetted in distilled water, was then carefully and lightly placed on the solution at the *c* side, and distilled water poured gently on to it, until a stratum, the eighth of an inch in thickness, appeared over the sulphate of magnesia. All was then left for a few minutes, that any solution adhering to the cork might sink away from it, or be removed from the water on which it now floated; and then more distilled water was added in a similar manner, until it reached nearly to the top of the glass. In this way, solution of the sulphate occupied the lower part of the glass, and also the upper on the right-hand side of the mica; but on the left-hand side of the division, a stratum of water from *c* to *d*, one inch and a half in depth, reposed upon it, the two presenting, when looked through horizontally, a comparatively definite plane of contact. A second platinum pole, *e*, was arranged so as to be just under the surface of the water, in a position nearly horizontal, a little inclination being given to it, that gas evolved during decomposition might escape. The part immersed was three inches and a half long by one inch wide; and about seven-eighths of an inch of water intervened between it and the solution of sulphate of magnesia.

(482) The latter pole, *e*, was now connected with the negative end of a voltaic battery, of forty pairs of plates, four inches square; whilst the former pole, *b*, was connected with the positive end. There was action and gas evolved at both poles; but, from the intervention of the pure water, the decomposition was very feeble, compared to what the battery would have effected in an uniform solution. After a while (less than a minute), magnesia also appeared at the negative side. *It did not make its appearance at the negative metallic pole, but in the water*, at the place where the solution and the water met; and on looking at it horizontally, it could be there perceived lying in the water upon the solution, not rising more than a fourth of an inch above the latter; whilst the water between it and the negative pole was perfectly clear. On continuing the action, the bubbles of hydrogen, rising upwards from the negative pole, im-

pressed a circulatory movement on the stratum of water, upwards in the middle, and downwards at the side, which gradually gave an ascending form to the cloud of magnesia in the part just under the pole, having an appearance as if it were there attracted to it; but this was altogether an effect of the currents, and did not occur till long after the phenomena looked for were satisfactorily ascertained.

(483) After a little while the voltaic communication was broken, and the platinum poles removed with as little agitation as possible from the water and solution, for the purpose of examining the liquid adhering to them. The pole *e*, when touched by turmeric paper gave no traces of alkali; nor could anything but pure water be found upon it. The pole *b*, though drawn from a much greater depth and quantity of fluid, was found so acid as to give abundant evidence to litmus paper, the tongue, and other tests. Hence, there had been no interference of alkaline salts in any way, undergoing first decomposition, and then causing the separation of the magnesia at a distance from the pole by mere chemical agencies. This experiment was repeated again and again, and always satisfactorily.

(484) Thus it is clearly shown, that both water and air may officiate as a *pole*, and that one *element or principle* only, has no power of transference, or of passing towards either pole; and hence there appears but little reason to consider the phenomena of electro-chemical decomposition, as due to the *attraction* or attractive powers of the metallic terminations of the battery. Indeed, if, in accordance with the usual theory, a piece of platinum be supposed to have sufficient power to attract a particle of hydrogen from the particle of oxygen with which it was the instant before combined, there seems, as Faraday has observed, no sufficient reason, nor any facts, except those to be explained, which show why it should not, according to analogy with all ordinary attractive forces, as those of gravitation, magnetism, cohesion, chemical affinity, &c., *retain* that particle which it had just before taken from a distance, and from previous combination. Yet it does not do so, but allows it to escape freely.

(485) It would not be possible, perhaps, to bring forward a more instructive, or a more beautiful instance of the *transfer of elements*, and their progress in opposite directions, parallel to the electric current, than is furnished by *chloride of silver* when decomposed by silver-wire poles. Upon fusing a portion of this compound on a piece of glass, and bringing the poles into contact with it, there is abundance of silver evolved at the negative pole, and an equal abundance absorbed at the positive pole, for no chlorine is set free; and by careful management the negative wire may be withdrawn from the fused globules as the silver is reduced there, the latter serving as

the continuation of the pole, until a wire or thread of revived silver, five or six inches in length, is produced. At the same time, the silver at the positive pole is as rapidly dissolved by the chlorine which seizes upon it, so that the wire has to be continually advanced as it is melted away. The whole experiment includes the action of only two elements—silver and chlorine.

(486) According to the theory of Faraday, no element or substance can be transferred, or pass from pole to pole, unless it be in chemical relation to some other element or substance tending to pass in the opposite direction, the effect being essentially due to the mutual relation of such particles. Thus, pulverized charcoal, or sublimed sulphur, diffused through dilute sulphuric acid, exhibits no tendency to pass to the negative pole, neither do spongy platinum, or gold precipitated by sulphate of iron; yet in these cases, the attraction of cohesion is almost perfectly overcome; the particles are so small as to remain for hours in suspension, and are perfectly free to move by the slightest impulse towards either pole; and *if in relation* by chemical affinity to any substance present, are powerfully determined to the negative pole.

(487) In Davy's celebrated paper on "*Some Chemical Agencies of Electricity*," read before the Royal Society, November 20th, 1806, the following experiments on the passage of acids, alkalies, and other substances through various attracting chemical menstrua, are described: "An arrangement was made, consisting of three vessels, as shown in Fig. 199: solution of sulphate of potash was placed in contact with the negatively electrified point, pure water was placed in contact with the positively electrified point, and a weak solution of ammonia was made the middle link of the conducting chain; so that no sulphuric acid could pass to the positive point in the distilled water without passing through the solution of ammonia: the three glasses were connected together by pieces of amianthus. A power of 150 pairs was used: in less than five minutes it was found, by means of litmus paper, that acid was collecting round the positive point: in half an hour the result was sufficiently distinct for accurate examination.

Fig. 199.



"The water was sour to the taste, and precipitated solution of nitrate of barytes.

"Similar experiments were made with solution of lime and weak solutions of potash and soda, and the results were analogous. With strong solutions of potash and soda a much longer time was required

for the exhibition of the acid; but even with the most saturated alkaline lixivium, it always appeared in a certain period. Muriatic acid, from muriate of soda, and nitric acid, from nitrate of potash, were transmitted through concentrated alkaline menstrua under similar circumstances. When distilled water was placed in the negative part of the circuit, and a solution of sulphuric, muriatic, or nitric acid, in the middle, and any neutral salt with a base of lime, soda, potash, ammonia, or magnesia, in the positive part, the alkaline matter was transmitted through the acid matter to the negative surface, with similar circumstances to those occurring during the passage of the acid through alkaline menstrua; and the less concentrated the solution the greater seemed to be the facility of transmission.

"I tried in this way muriate of lime with sulphuric acid, nitrate of potash with muriatic acid, sulphate of soda with muriatic acid, and muriate of magnesia with sulphuric acid; I employed the power of 150; and in less than forty-eight hours, I gained in all these cases decided results; and the magnesia came over like the rest.

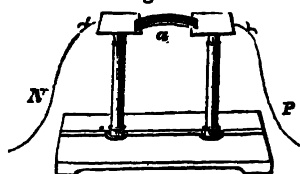
"Strontites and barytes passed like the other alkaline substances, readily through muriatic and nitric acids; and vice versâ, these acids passed with facility through aqueous solutions of barytes and strontites; but in experiments in which it was attempted to pass sulphuric acid through the *same menstrua*, or to pass barytes or strontites through this acid, the results were very different.

"When solution of sulphate of potash was in the negative part of the circuit, distilled water in the positive part, and a saturated solution of barytes in the middle, no sensible quantity of sulphuric acid existed in the distilled water after thirty hours, the power of 150 being used: after four days sulphuric acid appeared, but the quantity was extremely minute: much sulphate of barytes had formed in the intermediate vessel: the solution of barytes was so weak as barely to tinge litmus, and a thick film of carbonate of barytes had formed on the surface of the fluid. With solution of strontites the result was very analogous, but the sulphuric acid was sensible in three days.

"When solution of muriate of barytes was made positive by the power of 150, concentrated sulphuric acid intermediate, and distille water negative, no barytes appeared in the distilled water, when the experiment had been carrid on for four days; but much oxymuriatic acid had formed in the positive vessel, and much sulphate of baryte had been deposited in the sulphuric acid."

(488) Sulphate of barytes may be decomposed by employing two insulated discs of platinum, as in Fig. 200, one of which is to be put in communication with the negative, and the other with the positive

Fig. 200.



end of the pile: on each of these a few grains of finely powdered sulphate of barytes, moistened by a drop or two of water, is placed, and the discs connected by a few filaments of wet cotton; they should be within half an inch of each of each other: in a few minutes barytes will be evinced by test papers at the negative disc, and sulphuric acid at the positive.

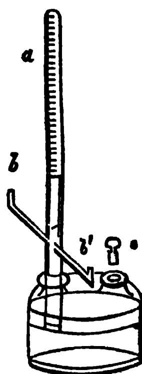
(489) These experiments of Davy's excited, at the time they were announced, the utmost astonishment; and the only way by which they could at all be explained, was by supposing that throughout the whole circuit, the natural affinities of substances were suspended and destroyed, but were again recovered when they were dismissed at the electrodes by which they were attracted. Faraday, however, denies that any such transfer of the constituents of the body decomposed can or does take place, and he applies the hypothesis of Grotthus to explain the *apparent* transfer. He maintains that there must be in all cases an unbroken series of particles of the electrolyte between the two electrodes; and that in those celebrated experiments of Davy's, in which the acid and alkaline constituents of the salt appear to be drawn through pure water, ammonia, &c., the decomposition could not have commenced until a portion of the salt had passed by capillary attraction across the syphons, so that a continuous line of saline particles was established between the electrodes. This explanation does not, however, appear to be satisfactory to some of the German and French electricians. Peschel, and especially Pouillet (*Elements de Physique*, vol. i. p. 598. 1847), still *maintain the transport* of the constituents of the electrolyte. "There is," says the latter, "at once a separation and a transport. Numberless attempts have been made to seize the molecule of water which has been decomposed, or to arrest *en route* the atoms of the constituent gases before their arrival at the electrodes, but without success. For example: if two cups of water, one containing the positive and the other the negative wire of a battery be connected by any conductor, singular phenomena will be observed. If the intermediate conductor be metallic, decomposition will take place independently in both cups; but if the intermediate conductor be the human body, as when a person dips a finger of one hand into the water in one cup, and a finger of the other hand into the other, the decomposition will sometimes proceed as in the case of a metallic connection: but more generally oxygen will be disengaged at the wire which enters the positive cup and hydrogen at the wire which enters the negative cup

no gases appearing at the fingers immersed in the one and the other. It would thus appear that one or other of the constituent gases must pass through the body of the operator in order to arrive at the pole at which it is disengaged." Is not this, however, intelligible on the theory of Grotthus, a chain of particles of water in the body of the experimenter forming the continuous line between the electrodes?

(490) When the material out of which the poles are formed is liable to the chemical action of the substances evolved, either simply in consequence of their natural relation to them, or of that relation aided by the influence of the current, they then suffer corrosion, and the parts dissolved are subject to transference in the same manner as the particles of the body originally under decomposition. Thus, platinum being made the positive and negative poles, in a solution of sulphate of soda, has no affinity for the oxygen, hydrogen, acid, or alkali evolved, and refuses to combine with, or retain them. Zinc can combine with the oxygen and acid: at the positive pole it does combine, and immediately begins to travel as oxide towards the negative pole. Charcoal, which cannot combine with the metals, if made the negative pole in a metallic solution, refuses to unite to the bodies which are ejected from the solution upon its surface; but if made the positive pole in a dilute solution of sulphuric acid, it is capable of combining with the oxygen evolved there, and consequently unites with it, producing both carbonic acid and carbonic oxide in abundance.

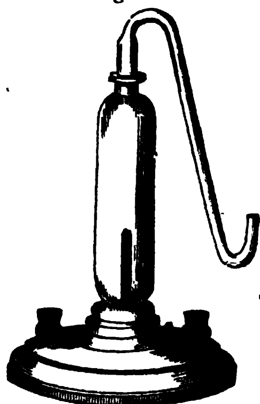
(491) Among the many grand discoveries with which Faraday has enriched electrical science, that of *definite electro-chemical action* is one of the most important. In the investigation of this question, it was necessary to construct an instrument which should measure out the Electricity passing through it, and which, being interposed in the course of the current used in any particular experiment, should serve at pleasure, either as a *comparative standard* of effect, or as a positive measurer of this subtile agent. Water, acidulated with sulphuric acid, was the electrolyte chosen, and Fig. 201 exhibits one of the forms of apparatus employed: *d* is a straight tube, closed at the other extremity and graduated: through the sides pass the platinum wires *b b′*, being fused into the glass and connected with two plates within: the tube is fitted by grinding into one mouth of a double-necked bottle, one half or two-thirds full of water, acidulated with sulphuric acid. The tube is filled by inclining the bottle; and when an electric current is passed through it, the gases evolved collect

Fig. 201.



in the upper part of the tube, and displace the diluted acid, the stopper *c* being left open. When the graduated part of the tube *a* is filled with the mixed gases, the electric circuit may be broken by removing the wires connected with *b b′*, the stopper *c* replaced, and the metre tube refilled, by properly inclining the instrument: a second measure of gas is then collected, on re-establishing the circuit, and so on. Fig. 202 is another very useful form of this instrument, to which its inventor has given the name of the *volta-electrometer.*

Fig. 202.



(492) By a series of experiments made with this apparatus, under a variety of forms, with different sized platinum electrodes, and with solutions of various degrees of strength, it was proved that water, when subjected to the influence of the electric current, is decomposed in a quantity exactly proportionate to the quantity of Electricity which passes through it, whatever may be the variations in the conditions and circumstances under which it may be placed; and hence, that the instrument may be employed with confidence as an exact measurer of voltaic Electricity.

(493) A voltameter, in which the electrodes are tin-plates coated with an alloy of lead and tin, has recently been described by Callan. (*Phil. Mag.*, N. S., vol. vii. p. 73.) The decomposing cell is of wrought-iron about an inch thick, made perfectly air-tight, the top consisting of an iron plate screwed down on an Indian-rubber collar; the gases are liberated through a stop-cock screwed on the top plate. The electrodes are arranged in two ways; for batteries of low intensity, 20 plates each 12 inches by 4 are employed; they are ranged parallel and separated $\frac{1}{16}$th of an inch from each other by strips of wood. Ten are connected with one end of the battery, and the other ten with the opposite end. The acting surface, including both sides of each plate, is about 3 square feet. The electrodes for batteries of high intensity, are likewise separated from each other by a non-conductor, but only the two terminal plates are connected with the poles of the battery. The cells are made perfectly water-tight, so that the battery current can only pass from one end of the battery to the other through the interposed plates and fluid. The number of cells should be about $\frac{1}{4}$th of the number of cells in the battery. Thus, for a battery of 12 cast-iron cells, there should be 3 cells or two plates between the two terminal plates; for a battery of 100

cast-iron cells in series, there may be 25 decomposing cells or 24 interposed plates. The intensity of a battery of 100 cells is 25 times greater than that of 4 cells, therefore the current from it will overcome 25 times the resistance, and will pass through 25 decomposing cells successively, as freely as a current from a battery of 4 cells will pass through a single decomposing cell, since there is as much of the mixed gases produced in each of the 25 decomposing cells as in the single cell through which the current from a battery of 4 cells passes. If the current from a battery of 100 cells arranged in one series, were sent through the electrodes as they are commonly arranged, the power of the battery would be exhausted about twice as soon as if the current passed through the electrodes arranged for batteries of high intensity, and the twelfth part of the full decomposing power of the battery would not be effective. Callan states, however, that it is better not to arrange a large battery *in series* for decomposing water, but in sets of four, because a faulty cell, or a bad zinc plate, will diminish considerably the power of the entire battery. The fluid used is a solution of an ounce and a quarter, or an ounce of carbonate of potash, soda, or ammonia (the latter best), in a quart of water: if more than an ounce and a quarter be used, the foam will be considerable; if less than an ounce, the conducting power will not be sufficient. The vessel must be tolerably capacious to allow the foam to accumulate, and the iron vessel in which the electrodes are contained should be coated with an alloy of lead and tin, or lead and antimony, in which the proportions of tin and antimony are small.

(494) Callan also describes an apparatus for applying the mixed gases to the production of the *lime* light for illuminating purposes: it consists of two wrought-iron vessels of unequal size; the smaller one is about 5½ inches high and 2 inches in diameter, the sides being an inch thick; the larger one is about 7½ inches high and 4 inches in diameter, the sides about ⅞ths of an inch thick. On the top of the vessel is laid a collar of thick vulcanized Indian-rubber; an iron plate about ¾ths of an inch thick is there screwed down to it by iron bolts; the vessel is thus made air tight: the top of this vessel is connected by an Indian-rubber tube with the bottom of the small one, the bottom is connected by a similar tube with the gas-bag, gas-holder, or voltameter: the two vessels are nearly filled with water: the gas is sent into the bottom of the large one, ascends through the water, passes through the tube to the bottom of the small one, then through the water, and issues from the jet screwed to the top of the small vessel. The two vessels being of unequal size, it is impossible that all the water should be carried out of both at the same time, by

the stream of the gases; and should an explosion occur after the small vessel becomes empty, the flame would be stopped by the water in the large vessel. In each vessel the gases are made to pass through wire gauze or perforated zinc, or through small pieces of porous earthenware, in order to break the bubbles, and thus prevent the gases from ascending in a continued series of large bubbles. To prevent the water from being driven into the gas-bag or voltameter, an Indian-rubber valve is placed across the hole through which gases enter. This valve opening only inwards, becomes closed by any expansive force acting outwards: no dangerous explosion can consequently happen with this apparatus. With a battery of twelve four-inch cast-iron cells, or of four cells, each 6×8 inches, Callan obtained a sufficient amount of gas for the supply of the gas micro scope, dissolving views, &c.; the lime light was ¼th of an inch in diameter and *constant*.

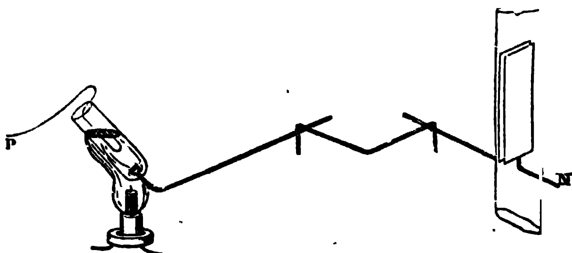
(495) The following observations on the relative practical values of the lime and coke lights are worth attention, as being the results of extensive experiments. If the jet of the gas-holder be attached to a stop-cock, by which the gases may be confined for 55 seconds in every minute, and if they are allowed to issue from the jet only for five seconds in each minute, *twelve* times as much of the gases must pass through the jet in these five seconds, as would pass through it in the same time were the stop-cock always open. Hence, if the gases produced by the battery are ignited for five seconds in each minute as they issue from this jet, and are confined in the voltameter for the remaining 55 seconds, the flame will, when thrown on lime, give a light *twelve times* as large as one a quarter of an inch in diameter, or one nearly ⅞ths of an inch in diameter. This is effected by means of a stop-cock of peculiar construction, the key of which is worked by clock-work. The expense of such an intermitting light would not be great, and it is particularly recommended for light-houses. The *constant* light seems at present almost impracticable. When *coke* is used and the light constant, the battery soon wears out. The coke light is more intense than the lime light, and somewhat less expensive; but the lime light is much more easily managed than the coke light.

To produce a coke light sufficient for all illuminating purposes, 40 cast iron cells, each containing a zinc plate, 2 inches by 4, will suffice. To obtain a lime light of equal illuminating power, a battery containing at least twice as large a surface of zinc will be required. The coke points will require to be changed more frequently than the lime, and there is more reason to fear that the coke light will fail, on account of the destruction of the positive coke point, than that the

lime will go out on account of the wearing of the lime. The smallest, and therefore the least expensive, battery by which, by the aid of a good apparatus for adjusting the coke points, a continuous light of great illuminating power can be obtained, Callan found to be 40 cells, in which the zinc plates were 2 × 4 inches. To produce an equal light from lime, a battery nearly twice the size would be required, the cells being arranged in sets of 4. The most effective method for arranging a cast-iron battery for the decomposition of water, is in sets of *four*. Callan found that 4 cells produced more than half the quantity of gases yielded by 12 of the same size, and that a battery of 60 cells working in series, produced in a minute, very little more than 4 of the same size. He thinks that there is a certain intensity, above and below which there is a loss of decomposing power, and that in the cast-iron battery when more than 4 cells are employed in series, some of the Electricity passes through the water without meeting the resistance or re-action necessary for decomposition. With a common voltameter, a battery of 500 cast-iron cells arranged in rows of *four* will produce more than 50 times as much gases as it will when the cells are arranged in series.

(496) A detail of one experiment with protochloride of tin (*Faraday's Experimental Researches*, 789), will be sufficient as an example, both of definite electro-chemical decomposition, and of the masterly method of examining the question which was adopted by Faraday.

Fig. 203.



A piece of platinum wire had one extremity coiled into a small knob; and, having been carefully weighed, was sealed hermetically into a piece of bottle-glass tube, so that the knob should be at the bottom of the tube within. The tube was suspended by a piece of platinum wire, so that the heat of a spirit-lamp could be applied to it. Recently fused protochloride of tin was introduced in sufficient quantity to occupy, when melted, about one-half of the tube. The wire of the tube was connected with a volta-electrometer, which was itself connected with the negative end of a voltaic battery; and a platinum wire connected with the positive end of the same battery was dipped

into the fused chloride in the tube, being however so bent, that it could not by any shake of the hand or apparatus, touch the negative electrode at the bottom of the vessel. The whole arrangement is delineated in Fig. 203.

(497) Under these circumstances, the chloride of tin was decomposed; the chlorine evolved at the positive electrode formed *bichloride* of tin, which passed away in fumes; and the tin evolved at the negative electrode combined with the platinum, forming an alloy fusible at the temperature to which the tube was subjected, and therefore never occasioning metallic communication through the decomposing chloride. When the experiment had been continued so long as to yield a reasonable quantity of gas in the volta-electrometer, the battery connection was broken, and the positive electrode removed, and the tube and remaining chloride allowed to cool. When cold, the tube was broken open, the rest of the chloride and the glass being easily separable from the platinum wire and its button of alloy. The latter, when washed, was then re-weighed, and the increase gave the weight of the tin reduced.

(498) The following are the particular results of one experiment: The negative electrode weighed at first 20 grains; after the experiment, it, with the button of alloy, weighed 23·2 grs. The tin evolved by the electric current at the cathode weighed therefore 3·2 grains. The quantity of oxygen and hydrogen collected in the volta-electrometer = 3·85 cubic inches. As 100 cubic inches of oxygen and hydrogen, in the proportions to form water, may be considered as weighing 12·92 grains, the 3·85 cubic inches would weigh 0·49742 of a grain: that being therefore the weight of water decomposed by the same electric current as was able to decompose such weight of protochloride of tin as could yield 3·2 grains of metal. Now, 0·49742 : 3·2 : : 9 (the equivalent of water) : 57.9, which should therefore be the equivalent of tin, if the experiment had been made without error, and if the electro-chemical decomposition *is in this case also definite.* In some chemical works, 58 is given as the chemical equivalent of tin; in others, 57·9. Both are so near to the result of the experiment, and the experiment itself is so subject to slight causes of variation, that the numbers leave little doubt of the applicability of the *law of definite action* in this and all similar cases of decomposition. Chloride of lead was experimented upon in a manner exactly similar, except that *plumbago* was substituted for platinum, as the positive electrode. The mean of three experiments gave 100·85 as the equivalent for lead: the chemical equivalent is 103·5, the deficiency being probably attributable to the solution of part of the gas in the volta-electrometer.

(499) In some experiments, several substances were placed in succession, and decomposed simultaneously by the same electric current: thus, protochloride of tin, chloride of lead, and water, were acted on at once, the results were in harmony with each other: the tin, lead, chlorine, oxygen and hydrogen evolved being *definite in quantity*, and electro-chemical equivalents to each other.

(500) By these and numerous other experiments, an irresistible mass of evidence was produced to prove the truth of the important proposition, that the chemical power of a current of Electricity is in direct proportion to the absolute quantity of Electricity which passes, which also is not merely true with one substance, as water, but generally with all electrolytic bodies; and farther, that the results obtained with any *one substance*, do not merely agree amongst themselves, but also with those obtained from *other substances*, the whole combining together into *one series of definite electro-chemical actions.*

(501) The following is a summary of certain points respecting electrolytes, iöns, and electro-chemical equivalents, developed by Dr. Faraday, and given in the seventh series of his Experimental Researches. (826, *et seq.*)

i. A single iön, that is, one not in combination with another, will have no tendency to pass to either of the electrodes, and will be perfectly indifferent to the passing current, unless it be a compound of more elementary iöns, and itself subject to decomposition. Upon this fact is founded much of the proof adduced in favour of the new theory of electro-chemical decomposition put forward in a former series of these Researches.

ii. If one iön be combined in right proportions with another strongly opposed to it in its ordinary chemical relations, that is, if an aniön be combined with a cathiön, then both will travel, the one to the anode, and the other to the cathode of the decomposing body.

iii. If therefore an iön pass towards one of the electrodes, another iön must be also passing simultaneously to the other electrode, though, from secondary action, it may not make its appearance.

iv. A body decomposable directly by the electric current, that is, an electrolyte, must consist of two iöns, and must give them up during the process of decomposition.

v. There is but one electrolyte composed of the same two elementary iöns, at least such appears to be the fact, dependent upon a law, *that only single electro-chemical equivalents of elementary iöns can go to the electrodes, and not multiples.*

vi. A body not decomposable when alone, as boracic acid, is not directly decomposable by the electric current when in combination; it may act as an iön, going wholly to the anode or cathode: but it

does not give up its elements, except occasionally by chemical action.

vii. The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-decomposition, either in kind or in degree; but it seriously influences, by secondary action, the state in which the iöns finally appear. Advantage may be taken of this principle, in combining and collecting such iöns, as, if evolved in their free state, would be unmanageable.

viii. A substance which, being used as the electrode, can combine altogether with the iön evolved against it, is also an iön, and combines in such cases in the quantity represented by its electro-chemical equivalent. All the experiments agree with this view, and it seems, at present, to result as a necessary consequence. Whether in the secondary action that takes place where the iön acts, not upon the matter of the electrode, but upon that which is round it in the liquid, the same consequence follows, will require more extended investigation to determine.

ix. Compound iöns are not necessarily composed of electro-chemical equivalents of simple iöns. For instance—sulphuric, phosphoric, and boracic acids, are iöns, but not electrolytes, that is, not composed of electro-chemical equivalents of simple iöns.

x. Electro-chemical equivalents are always consistent, that is, the same number which represents the equivalent of a substance A, when separating from a substance B, will also represent A when separating from a third substance C. Thus 8 is the electro-chemical equivalent of oxygen, whether separating from hydrogen, or tin, or lead; and 104 is the electro-chemical equivalent of lead, whether separating from oxygen, chlorine, or iodine.

xi. Electro-chemical equivalents coincide, or are the same with ordinary chemical equivalents.

(502) The theory of definite electro-chemical action led Faraday to the consideration of the absolute quantity of electric force in matter: for although, as he observes, we are utterly ignorant of what an atom really is, we cannot resist forming some idea of a small particle, which represents it to the mind, and there is an immensity of facts which justify us in believing that the atoms of matter are in some way endowed or associated with electrical powers to which they owe their most striking qualities, and amongst them their mutual chemical affinity. Now, to decompose a single grain of acidulated water, an electric current, powerful enough to retain a platinum wire $\frac{1}{104}$ of an inch in thickness, red-hot, must be sent through it for three minutes and three quarters, and this quantity of Electricity is

equal to a very powerful flash of lightning: yet the electrical power which holds the elements of a grain of water in combination, or which makes a grain of oxygen and hydrogen, in the right proportions, unite into water when they are made to combine, equals, in all probability, the current required for the separation of that grain of water into its elements again; and this Faraday has shown to be equal to 800,000 charges of a Leyden battery of fifteen jars, each containing one hundred and eighty-four square inches of glass, coated on both sides: indeed, a beautiful experiment is described by Faraday, in which the chemical action of dilute sulphuric acid on 32·31 parts, or one equivalent of amalgamated zinc, in a simple voltaic circle, was shown to be able to evolve such quantity of Electricity in the form of a current, as passing through water could decompose nine parts, or one equivalent of that substance; thus rendering the proof complete (bearing in mind the definite relations of Electricity), *that the Electricity which decomposes, and that which is evolved by the decomposition of, a certain quantity of matter, are alike.*

(503) *Secondary Results:*—In investigating the action of the voltaic current on chemical compounds, it is important to distinguish carefully between *primary* and *secondary* results. When a substance yields, uncombined and unaltered at the electrodes, those bodies which have been separated by the electric current, then the results may be considered as primary; but when any second re-action takes place, by which the substances, which appear at the electrodes, are *not* those which the *immediate* decomposition of the compounds would produce, then the results are secondary, although the bodies evolved may be elementary.

These secondary results occur in two ways, being sometimes due to the mutual action of the evolved substance on the matter of the electrode, and sometimes to its action on the substances contained in the body itself, under decomposition. Thus, when carbon is made the positive electrode in dilute sulphuric acid, carbonic oxide, and carbonic acid occasionally appear there instead of oxygen: for the latter acting on the matter of the electrode, produces these secondary results. Or if the positive electrode, in a solution of nitrate, or acetate of lead, be platinum, then peroxide of lead appears there equally a secondary result with the former; but now depending upon an action of the oxygen on a substance in the solution. Again, when ammonia is decomposed by platinum electrodes, nitrogen appears at the anode; but though an *elementary* body, it is a *secondary* result in this case, being derived from the chemical action of the oxygen, electrically evolved there upon the ammonia in the surrounding solution. In the same manner, when aqueous solutions of metallic salts are

electrolyzed, the metals evolved at the cathode, though elements, are always secondary results, and not immediate consequences of the decomposing power of the electric current.

(504) By the aid of feeble electric currents, some interesting decompositions and crystallizations were obtained by Becquerel. The following are some of his results:* *suboxide of copper* in the form of small bright octohedrons of a deep red colour was obtained by filling a tube with solution of nitrate of copper, placing at the bottom some powdered protoxide, and plunging into the liquid a plate of copper. The tube being then hermetically sealed, the crystals made their appearance after about ten days. That part of the plate which was in contact with the protoxide was *positive*, and the other part *negative*. If there was excess of protoxide, the solution after a time became colourless. Crystallized *protoxide of lead* was obtained by placing at the bottom of a tube some pulverized litharge, and pouring over it a slightly diluted solution of sub-acetate of lead, then plunging into it a plate of lead which was equally in contact with the litharge; the tube was then hermetically sealed, and the surface of the plate became gradually covered with small prismatic needles of hydrate of lead. Crystallized *oxide of zinc* was obtained in the following manner: two bottles were filled, one with a solution of zinc in potash, and the other with a solution of nitrate of copper, a communication was established between them by means of a bent tube filled with potter's clay, moistened with a solution of nitrate of potash; a plate of lead was immersed in the solution of zinc, and a plate of copper in the solution of copper: these two plates were put in metallic communication with each other. The nitrate of copper was decomposed in consequence of the action of the current proceeding from the action of the alkali on the lead: the oxygen and the nitric acid were transferred to the plate of lead, and there produced nitrate of potash and oxide of lead, which was dissolved in the alkali. After the experiment had been continued some days, small clear crystals, having the shape of flat prisms, and so disposed as to form rosettes, were found deposited on the plate of lead. Crystallized *hydrate of lime* was obtained by filling a V shaped tube, the lower part of which was plugged with moist clay with *Seine* water, which contains sulphate of lime, and passing the current from fifteen elements through the liquid, both the water and the sulphate of lime were decomposed; that in the negative branch became alkaline, and a

* Traité de Electricite, vol. iii. p. 287, *et seq.*
Taylor's Scientific Memoirs, vol. i. p. 414.
Comp. Rend. Feb. 1852.
L. and E. Phil Mag., N. S., vol. iii. p. 235.

crystalline deposit gradually took place. *Chloride of silver* was obtained, in the form of beautiful translucent octohedrons, by immersing a plate of silver attached by a wire of the same metal to a piece of charcoal, in a tube containing concentrated hydrochloric acid, and nearly closed. The silver attracted and combined with the chlorine, and the hydrogen of the acid formed, with the charcoal, a gaseous compound, which escaped. With a similar arrangement, substituting copper for silver, fine tetrahedral crystals of *chloride of copper* were formed after a few months' action. Becquerel also succeeded in forming, artificially, by slow electric action, *the sulphurets of silver, copper, lead, and tin,* in beautifully crystalline forms.

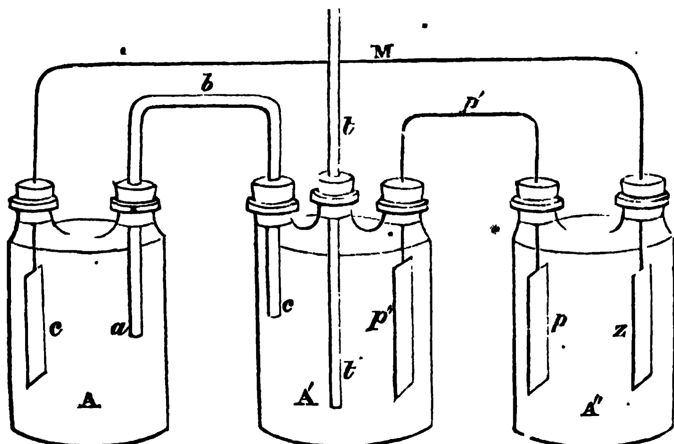
(505) More recently the weak actions to which Becquerel's attention has been more particularly directed, are those which commence as soon as the rocks, the metallic and other substances which occupy veins and beds, come in contact with the mineral waters which rise from all parts of the earth's interior. *Time*, then, becomes an element in the growth of the crystalline substances formed. The following experiments were made: 1°. A plate of amalgamated zinc surrounding a copper wire was plunged in a solution of silica in potash. After a fortnight's action, very small, regular, octohedral crystals of *hydrate of zinc* were formed on the zinc plate; 2°. A lead-copper arrangement was substituted for the zinc copper, anhydrous crystals of *oxide of lead* were deposited on the lead plate; 3°. Lumps of *galena* were left for several years in solutions of chloride of sodium and sulphate of copper; the following products were formed, either on the galena or on the bottom and sides of the vessel: a, *chloride of sodium* in cubes, cubic octohedrons, and even in octahedrons, having great transparency and very definite forms; b, *chloride of lead,* in needles and cubes, slightly yellowish and of a very perfect form; c, *sulphate of lead* in cuneiform octohedrons, much modified, precisely resembling the crystalline sulphate of lead of Anglesea; d. *chloro-sulphate of lead, in needles*; e. *basic chloride of lead* in microscopic crystals disseminated here and there throughout the whole product; f. *sulphuret of copper*, black, without an appearance of crystallization. The whole of these substances covering the piece of galena gave it the appearance of a specimen from a mineral vein. A voltaic couple formed of a piece of galena surrounded by a platinum wire placed in a saturated solution of common salt and sulphate of copper diluted with three volumes of water, give rise to the formation of a considerable quantity of *crystallized chloride of lead* in cubes without any other product.

Becquerel thinks that these re-actions take place in nature; rain water, coming into contact with mineral masses and veins formed of

metallic combinations, becomes charged with chloride of sodium and sulphate of copper arising from the decomposition of copper pyrites; the resulting solutions once in contact with galena, re-act upon it weakly, and give rise to the various compounds above described.

(506) To obtain in a crystalline state sulphur, sulphate, and carbonate of baryta, the apparatus shown in Fig. 204 was employed.

Fig. 204.



A., A', A'' are three Wolfe's bottles; A contains a solution of sulphate of copper, A' a solution of the substance in the constituent parts of which it is desired to introduce a change, and A'' contains water, rendered a conductor by the addition of an acid or common salt. A communicates with A' by means of a bent tube, *a b c*, filled with potter's clay or plaster of Paris, as suggested by Dr. Golding Bird, moistened with a saline solution, the nature of which depends on the effect intended to be produced in A. A' and A'' communicate with each other by means of the two platina plates, *p p'* and A and A'' communicate by means of a voltaic pair *c* M *z*: *t t* is a safety tube, to indicate internal pressure arising from the disengagement of gas.

According to this arrangement, the extremity *p''* of the platina plate is the positive pole of a voltaic apparatus, whose action is slow and continuous when the liquid in A' is a good conductor; the intensity of the electric forces is sufficient to decompose the sulphate of copper in A; from that instant the oxygen proceeds towards *a* as well as the sulphuric acid, which, in passing into the tube *a b c*, expels those acids which have a less affinity than itself towards the bases. These acids and the oxygen pass into the liquid A', where their slow re-actions determine the relative changes in the bodies which they

find there. On introducing in A' an alcoholic solution of sulpho carbonate of potash, and moistening the clay in the tube *a b c* with a solution of nitre, a crystalline deposit of *sulphur and carbonate of potash* took place on the platinum plate *p''* after 24 hours' action, when a solution of sulpho-carbonate of baryta was substituted for sulpho-carbonate of potash, the deposit consisted of crystals of sulphur, and carbonate, and sulphate of baryta. A' was filled with a solution of *sulphite of potash, p p' p''* being a double plate of copper. The extremity *p''*, which was still the positive pole, attracted the oxygen and the nitric acid, the latter decomposed the sulphite and took possession of the base: the sulphurous acid was carried to the oxide of copper, which was formed at the same time and combined with it. The sulphite of copper combined with the sulphite of potash, and formed a double compound, which crystallized in beautiful octohedrons, but which was gradually decomposed, and gave place to fine transparent octahedral crystals of sulphite of copper, of a vivid red colour, and with the brilliancy of garnets.

(507) By the following arrangement, recommended by Dr. Golding Bird, fine crystals of *copper, of suboxide of copper*, and *of oxide of zinc*, may be obtained: A glass tube, open at both ends, about half an inch in diameter and three inches in length, is closed at one end by means of a plug of plaster of Paris, about $\frac{1}{8}$ of an inch in thickness. The tube is filled with a moderately diluted solution of nitrate or chloride of copper, and placed inside a cylindrical glass vessel, nearly filled with a weak solution of potash or soda. The leaden leg of a compound lead and copper arc is plunged into the outer cylinder, and the copper leg into the tube. The lead slowly dissolves in the alkaline solution, and electric action is set up; the current traverses the plaster of Paris partition, and the oxide of copper (precipitated by the slow admixture of the alkaline solution with the copper salt) is reduced partly to the metallic state and partly to suboxide, both of which crystallize on the negative copper leg of the arc. If a solution of oxide of zinc in caustic potash be substituted for the uncombined alkali in the larger vessel, a very elegant deposit of *oxide of zinc* takes place in about eight or ten days, on the lead or positive plate, while fine crystals of copper and suboxide are deposited on the copper or negative plate.

(508) The following experiments were made by Mr. Crosse:

1°. In an oval glass dish, of the capacity of about two quarts, was placed, on the bottom horizontally, a flat piece of clay-slate, a few inches square, with a platinum wire round its middle, and connected with the negative pole of a *sulphate of copper battery* of eight pairs of plates. Upon this was placed a piece of mountain limestone, of a

few ounces' weight, round the middle of which passed a platinum wire, connecting it with the positive pole. This stone was prevented from touching the slate below by three small wedges of deal, placed as supports. The glass dish was filled with spring water, and a stream of gas was rising from each wire. After two months' action the negative platinum wire was entirely covered throughout its whole length, under water, with *crystalline carbonate of lime*, and the positive wire had produced a great effect upon that part of the limestone with which it was in contact, having *eaten into* it so as to form a neck round it. In another month the effects greatly increased, and carbonate of lime began to form rapidly over the whole of the slate, as well as over the greater part of the inner surface of the glass basin. It so happened that the most elevated part of the limestone stood perpendicularly above a part of the negative wire, from which a constant stream of hydrogen gas, in minute bubbles, was playing against the little wall of limestone above it. Exactly where this line of bubbles existed, about half an inch in width, was a line of most beautiful translucent crystals of carbonate of lime upon the limestone, and occupying the whole surface of that part of it which was exposed to the current of hydrogen gas.

2°. In a glass jar of spring water were placed two pieces of clay slate, and between them a piece of crystallized carbonate of strontia, connected with the positive pole of a sulphate of copper battery, of six pairs of plates, the lower slate being in connection with the negative pole: both slates became thickly covered with pearly-white carbonate of strontia in a botryoidal formation: the glass was also partially covered with stalactitic carbonate of strontia.

3°. In a similar jar, carbonate of barytes was positively electrified: the negative wire and a portion of the slate became gradually covered with a beautiful mamillated formation of carbonate of barytes.

4°. In a similar jar, sulphate of barytes was positively electrified: the slate was studded with brilliantly transparent crystals of sulphate of barytes.

5°. A piece of solid opaque white quartz, suspended in a glass basin, filled with solution of pure carbonate of potash, was kept positively electrified by a similar battery, a similar piece of quartz being in the same manner kept negative. Some small pieces of quartz were placed between the two: after some months' action there was a considerable formation of crystals.

(509) Among the results obtained by the author, the following are worthy of being recorded:—

1°. Two pieces of white marble, placed horizontally in a glass basin, were connected by platinum wires with the positive and nega-

tive terminations of a battery of twenty pairs, in glass jars, charged with salt and water. The basin was filled with spring water,: after several months' action the positive marble was cut nearly half through its thickness, and the edges of the negative marble, and the negative side of the basin, were covered with myriads of crystals. A strong smell *of chlorine* was perceptible, evidently occasioned by the decomposition of the chlorides contained in the water. Mr. Crosse noticed the same in some of his experiments, and there is no doubt, as he remarks, that the small quantity of chlorine thus evolved at the positive pole, lent material assistance to the transference.

2°. The positive platinum wire of a similar battery was twisted round a piece of mountain limestone; the negative wire was attached to a piece of slate: after the lapse of several months the limestone was cut nearly in two, and the slate was beautifully studded with crystals of carbonate of lime.

3°. To the positive pole of a battery of twenty pairs, charged with salt and water, was attached a crystal of sulphate of barytes. This rested on the bottom of an inverted gallipot, which was placed in a large glass jar filled with spring water. After six months' action the negative side of the gallipot had become studded with *beautiful transparent crystals*, many of which could be distinctly pronounced to be four-sided and tabular. These crystals rapidly increased, both in size and number, and after twelve months' action the jar itself, and also the slate, were completely covered with crystals.

4°. Under similar circumstances (except that instead of a gallipot a small inverted tumbler was employed), a crystal of *sulphate of strontia* was kept positively electrified; there was a similar formation of transparent crystals over the negative side of the inverted jar, and also over the side of the large jar in which the whole was placed. The odour of chlorine was in both these experiments very distinct.

5°. The carbonates of barytes and strontia kept positively electrified in vessels of spring water, after several months' action, transferred beautiful crystals to the negative side of the basin; and, in the case of the carbonate of strontia, the negative slate was very thickly studded; the evolution of chlorine was very evident in both cases.

6°. A common large garden flower-pot *without* a hole in the bottom, was filled with fragments of common red-brick, and placed on two pieces of brick standing in a common salting pan: the pot was kept filled with spring water, the droppings being poured back every morning. Three platinum wires from the positive extremity of a salt-and-water battery, of sixty pairs of cylinders, in three series of twenty pairs each, enveloped two of the pieces of brick, about three inches beneath the surface; and three silver wires from the negative

extremity were twisted round two other pieces at the opposite side of the pot. A few days after the commencement of the experiment, a strong odour of chlorine rose from the positive side; and, after the lapse of several months, there was a large accumulation of carbonate of lime on the negative side of the pot, not only over the fragments of brick, but all over the *outside* of the pot, and between the bottom of the pot and the crucible under the negative side. With the aid of a lens, a large accumulation of small crystals of carbonate of lime could be seen between the interstices of the bricks.

This experiment is a modified repetition of one of Mr. Crosse's experiments, which was as follows:—

In a large, common, glazed salting-pan, filled with the spring water of the country, a common red brick was laid horizontally, each end resting on a half brick of the same sort. The two ends of the brick were connected respectively with the positive and negative terminations of a sulphate of copper battery, of nine pairs of nine-inch plates: the upper surface of the brick was covered with clear river-sand. At the termination of a quarter of a year, the apparatus was taken apart, and the following observations were made:—

On attempting to lift the whole brick from the two half bricks that supported it, it was found that while the positive end was easily removed from the brick below it, the negative end required some little force to separate it from its support; and when the two were wrenched asunder, it was observed that they had been partially cemented together by a tolerably large surface of beautiful snow-white crystals of *arragonite*, thickly studding that part of the brick in groups, the crystals of each radiating from their respective centres. Here and there were formed in some of the little recesses in the brick, elevated groups of needle arragonite, meeting together in a pyramidal form in the centre; while, in the open spaces between, were some exquisitely-formed crystals of carbonate of lime in cubes, rhomboids, and more particularly in short six-sided prisms, with flat terminations, translucent and opaque, sufficiently large to determine their form without the use of a lens. The positive end of the brick and that which supported it were also covered with crystals, much smaller and apparently of a different nature. On emptying the water from the pan, there was found at its negative end, at the bottom, a very large quantity of snow-white carbonate of lime to the extent of some ounces in weight, in the form of a gritty powder in minute crystals. Three-fourths of the whole interior of the pan were covered with myriads of crystals of carbonate of lime, so firmly adhering to the pan, as not to be separated without the aid of an acid.

(510) Of the action of a weak acid on limestone, when concentrated at the positive pole, the following pretty application was made by Mr. Crosse:—

In a saucer, filled with a concentrated solution of nitrate of potash, a flat, polished piece of white marble was placed; and upon the middle of the marble, a common sovereign, with its reverse in contact with the marble, and having a stout glass rod supported perpendicularly on the coin, to keep it in its place. Between the rod and the coin was affixed a platinum wire, which was connected with the positive pole of a sulphate of copper battery, of eight pairs of plates; while round the marble, but not touching it, was a coil of similar wire connected with the negative pole. The nitric acid was soon separated from the potassa, and attacked the marble in contact with the sovereign; and, at the expiration of three days, *the coin was perfectly imbedded in the marble.* The experiment was then put an end to, and the marble being taken out and inverted, the sovereign fell out of its stony receptacle, leaving a tolerably perfect impression on the marble. A very singular result took place in this experiment: the end of the glass rod which rested on the platinum wire in contact with the coin, chanced to be ground for the length of about two inches, which ground portion at the termination of the experiment became permanently gilded. This was at first referred by Mr Crosse to the presence of a minute portion of chlorine in the solution; the real cause was detected in the course of the following experiments, made some years afterwards and communicated by Mr. Crosse to the chemical section of the British Association, in 1854, in a paper, "On the Apparent Mechanical Action accompanying Electric Transfer."

"*Experiment the first.*—I placed a piece of smooth carbonate of lime, of two inches square and half an inch thick, at the bottom of a rather deep saucer, which I nearly filled with dilute pure nitric acid. The preparation of the acid being one-fiftieth part by measure of the distilled water employed, which was one pint. Upon this piece of limestone I placed a sovereign, which weighed 123 grains, and upon the upper surface of the coin I placed one end of a platinum wire, which was connected with the *positive* pole of a small sustaining sulphate of copper battery. This end of the wire was kept firm on the coin, and the coin on the limestone by a stick of glass, supported vertically. The lower end of the stick was ground, as in my former experiment. Around the square piece of limestone I coiled a second platinum wire which was connected with the *negative* pole of the battery.

"The action commenced, hydrogen gas being liberated at the latter

pole, and carbonic acid gas from that part of the coin in contact with the limestone at the positive pole. I kept this in action for fifty hours, and then took the apparatus apart. The coin had sunk into the limestone to the depth of half its thickness, and when removed, it left a clean impression on the stone. But the most striking circumstance was that the carbonic acid gas in its evolutions from the stone, had struck off a portion of the milled edge of the sovereign, leaving it quite smooth at that part, and the pieces *broken* off had the milled edge remaining on them. Moreover, the evolution of gas carried up a small portion of gold, and gilded the whole of the ground surface of the glass rod. The broken pieces of metal lay around the coin, which when weighed, showed a loss of three grains, which was exactly the weight of the pieces, including the gilding on the glass, which I carefully removed. It is particularly to be noticed, this was at the *positive* pole. On testing the fluid, it evinced not a trace of *gold* or *copper*, but merely a portion of nitrate of lime. Indeed had either of these metals been in solution, they must have appeared on the *negative* platinum wire, which was not the case.

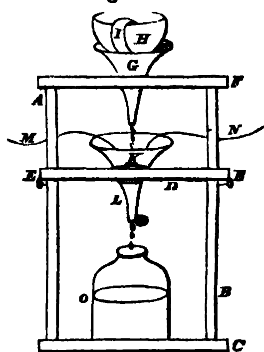
"*Experiment the second.*—I repeated the former experiment in a different manner, using pure sulphuric acid instead of nitric, and acting on the same sovereign, which now weighed 120 grains. This I placed on a larger piece of marble and kept it pressed firm in its position by a glass weight of larger diameter than the former, and weighing about two pounds. Instead of a saucer I used a glass jar, filling it with one ounce of sulphuric acid and forty-nine of distilled water, so that the pressure of the fluid was of course greater, from the greater depth of the vessel containing it, and resistance to the extrication of the gas was in consequence proportionably greater. I employed a sulphate of copper battery of eight pairs, weakly charged but in good action. This action was continued for ninety hours, and then stopped. The coin weighed 114 grains, having lost six grains, which lay in pieces around it upon the surface of the marble, and which weighed exactly six grains. The glass weight in this experiment was not gilded, and the coin had made but little impression on the marble. On examining the sovereign, I found that one portion of its edge had the entire milling completely removed, and that part of the edge was left perfectly smooth, the remaining part of the coin being little if at all acted on. In fact, neither of the flat sides of the coin was at all acted on; with the exception of a small portion of *both* sides which were contiguous to that part of the edge from which the entire milling was removed. The carbonic acid gas which was liberated from the limestone had found an easier vent from under one part of the coin than the other, and from this part it poured

forth in considerable quantity, and by its *constant friction* broke off small pieces of the coin, which lay in a heap adjoining. I must observe that a very minute quantity of the purple oxide of gold stained a part of the marble. In this latter experiment I placed a glass strip, of three-fourths of an inch wide and some inches in length, upon the two opposite edges of the glass jar containing the dilute acid, and half an inch above the surface of the fluid, as I expected a crystallization of sulphate of lime upon its under surface. I was not disappointed, as the whole of the glass was covered with hundreds of needle crystals of sulphate of lime from one end to the other. The glass strip was placed in a line exactly corresponding to the line of passage of the electric current, one end being over the *positive* wire, and the other over the *negative*; but every one of the crystals was at *right angles to the electric current*, viz., in the *magnetic direction*.

"In the electric transfer of the earthy carbonates, and probably of many other substances, the *mechanical* action of the gases evolved at *both* poles of the voltaic battery is strikingly shown by supporting a piece of clay-slate in a horizontal position, a few inches above each termination; taking care that such piece of clay-slate is somewhat below the surface of the fluid employed. In this way I have obtained crystals of the carbonates of lime, strontia, and baryta, on the under part of the clay-slate, suspended above *both* the positive and negative terminations of the battery. The deduction I draw from these experiments is, that a constant disturbance of the fluid electrically acted on, is a powerful agent in the formation of minerals, and in modifying the forms of matter. Some persons of high scientific authority have suggested that this power may possibly account for various hitherto unexplained phenomena in nature. It is my intention to pursue this subject in its different bearings."

(511) It was in the course of his experiments on electro-crystallization, that that extraordinary insect about which so much public curiosity was at the time expended, was first noticed by Mr. Crosse. The following is his account of the experiment in which it first made its appearance: A wooden frame was constructed, of about two feet in height, consisting of four legs proceeding from a shelf at the bottom, supporting another at the top, and containing a third in the middle. *A B*, Fig. 205, represents two of the four uprights, or legs, issuing from the base *C*, supporting the moveable shelf

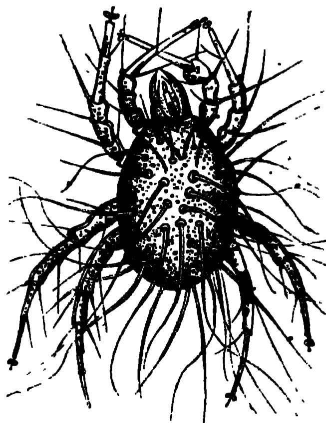
Fig. 205.



D, which shelf is kept in its place by four pins *E*, passing through the four uprights, and may be raised or lowered at pleasure. Each of these shelves was about seven inches square. The upper shelf was pierced with an aperture in which was fixed a funnel of Wedgewood ware, *G*, within which rested a quart basin, on a circular piece of mahogany placed within the funnel. When this basin was filled with fluid, a strip of flannel, wetted with the same, was suspended over the edge of the basin and inside the funnel, which, acting as a syphon, conveyed the fluid out of the basin through the funnel in successive drops. The middle shelf of the frame was likewise pierced with an aperture, in which was fixed a smaller funnel of glass, *L*, containing a piece of somewhat porous red oxide of iron from Vesuvius, *K*, immediately under the dropping of the upper funnel. This stone was kept constantly electrified by means of two platinum wires, *M N*, on either side of it, connected with the poles of a voltaic battery of nineteen pairs of five-inch zinc and copper plates, excited by water only. The lower shelf supported a wide-mouthed bottle *o*, to receive the drops as they fell from the second funnel. When the basin was nearly emptied, the fluid was poured back again from the bottle below into the basin above, without disturbing the position of the stone. The fluid with which the basin was filled was made as follows:—A piece of black flint was reduced to powder, having been first exposed to a red heat, and quenched in water. Of this powder, two ounces were taken and fused with six ounces of carbonate of potash: the soluble glass formed was dissolved in boiling water, diluted, and hydrochloric acid added to supersaturation, the object being to form, if possible, crystals of silica at one of the poles of the battery. On the fourteenth day from the commencement of the experiment, Mr. Crosse observed, through a lens, a few small whitish excrescences or nipples, projecting from about the middle of the electrified stone, and nearly under the dropping of the fluid above. On the eighteenth day these projections enlarged, and seven or eight filaments, each of them longer than the excrescence from which it grew, made their appearance on each of the nipples. On the twenty-second day these appearances were more elevated and distinct; and on the twenty-sixth day each figure assumed the form of a *perfect insect*, standing erect on a few bristles which formed its tail. Till this period Mr. Crosse had no notion that these appearances were any other than an incipient mineral formation; but it was not until the twenty-eighth day, when he plainly perceived these little creatures move their legs, that he felt any surprise. When an attempt was made to detach them from the stone, they immediately died; but in a few days they separated themselves, and moved about at pleasure. In the course

of a few weeks about a hundred of them made their appearance on the stone: at first, each of them fixed itself for a considerable time in one spot, appearing to feed by suction, but when a ray of light from the sun was directed upon it, it seemed disturbed, and removed itself to the shaded part of the stone. . . . . Mr. Crosse adds, "*I have never ventured an opinion as to the cause of their birth;* and for a very good reason—I was unable to form one. The most simple solution of the problem which occurred to me was, that they arose from *ova* deposited by insects floating in the atmosphere, and that they might possibly be *hatched* by the electric action. I next imagined, as others have done, that they might have originated from the water, and consequently made a close examination of several hundred vessels filled with the same water as that which held in solution the silicate of potassa. In none of these vessels could I perceive the trace of an insect of that description. I likewise closely examined the crevices and most dusty parts of the room with no better success."

Fig. 206.



(512) In subsequent experiments, this same insect (which it appears is of the genus acarus, but of a species not hitherto observed, and of which a magnified representation is given in Fig. 206) made its appearance in electrified solutions of *nitrate and sulphate of copper, of sulphate of iron, and sulphate of zinc;* also on the wires attached to the poles of a battery working in a concentrated solution of silicate of potassa, as shown in Fig. 207; also in *fluo-silicic acid,* in

Fig. 207.

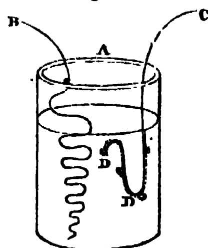


Fig. 208.

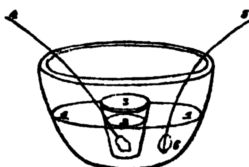
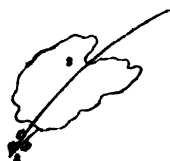


Fig. 209.



the arrangement shown in Fig. 208, in which a glass basin is shown partly filled with fluo-silicic acid, to the level 1 : 2, a small porous

pan made of the same materials as a garden-pot, partly filled with the same acid to the level 2, with an earthen cover, 3, placed upon it to keep out the light, dust, &c.: 4, a platinum wire connected with the positive pole of the battery, with the other end plunged into the acid in the pan, and twisted round a piece of common quartz; the platinum wire passes under the cover of the pan: 5, a platinum wire connected with the negative pole of the same battery, with the other end dipping into the basin an inch or two below the fluid, and, as well as the other, twisted round a piece of quartz. After eight months' action, Mr. Crosse perceived two or three insects in their incipient state, appearing on the naked platinum wire at the bottom of the quartz *in the glass basin at the negative pole.* In Fig. 209 a magnified view is given of the wire, &c., 1 being the platinum wire; 2, the quartz; 3, the incipient insects. At the suggestion of Mr. Crosse, some of these experiments were repeated by the late Mr. Weekes, of Sandwich, by passing currents of Electricity through vessels filled with solutions of silicate of potash, under glass receivers inverted over mercury, the greatest possible care being taken to shut out extraneous matter, and in some cases previously filling the receivers with oxygen gas. The general result was, that after an uninterrupted action of upwards of a year, insects made their appearance in every respect perfectly resembling those which occurred in the Broomfield experiments, as the author can testify, having had many opportunities of examining each. In some of Mr. Weekes's later experiments, the acarus made its appearance in solution of ferrocyanuret of potassium. Similar experiments were made by the author, and were continued for upwards of sixteen months. He did not succeed in obtaining the insects *within* the bell jars which covered the solutions undergoing electrolysis, but several, precisely similar to those of Crosse and Weekes, were repeatedly found on, and about, the terminal cells of the battery.

(513) The following account of some of his more recent experiments, in which acari made their appearance, has been kindly communicated by Mr. Crosse:—

"I calcined black gun flints, in a crucible, flung them while hot into water; I then dried and reduced them to powder. Of this powder I took one ounce, to which I added three ounces of carbonate of potassa, and intimately mixed them. I then projected the whole by separate portions, into a heated crucible, till the whole was in perfect fusion, which fusion I kept up for five hours, increasing the heat until it exceeded that sufficient to melt cast iron. I then removed the crucible and allowed the contents to become solid, which formed into a pale green transparent glass; while still *hot*, I

broke them into pieces. These *hot* pieces I threw into a vessel of boiling distilled water, which entirely dissolved them, and I took care that the water should be nearly saturated: we will call this silicate of potassa A: and I made use of it, as hereafter described, whilst it was still *hot*. I had previously prepared an apparatus to act electrically upon this fluid. It consisted of a common tubulated glass retort, supported in a frame contrived to keep it in the same position as when used in distillation. The beak or long end of this retort rested in a small cup of pure mercury, from which proceeded a platinum wire, which passed up through the whole length of the retort, and when it reached the bulb, was bent at right angles, so as nearly to touch the bottom of the bulb. The glass tube, which fitted air tight into the neck of this retort, had a platinum wire passed straight through it, the upper part of which was hermetically sealed into the upper part of the tube, and the lower part of the wire was continued downwards so as nearly to touch the bottom of the bulb. These two platinum wires were thus placed parallel to each other within the bulb of the retort, and at the distance of about two inches from each other. The wire which passed through the neck was then connected with the positive pole of a small sustaining sulphate of copper battery of six pairs of cylinders; and the mercury, from which proceeded the longer wire, which passed through the whole length of the retort, was connected with the negative pole. Of course no electric action could take place, until the bulb of the retort was filled more or less with a conducting medium. When all was ready I poured the solution A, still *hot*, into the bulb of the retort, having temporarily removed the tube in the neck for that purpose, and carefully fitted it again, it being accurately ground so as to fit air-tight. The bulb was about one-half filled with A. As soon as the bulb was filled as related, an electrical action commenced at both wires. Oxygen and hydrogen gases were liberated: the volume of atmospheric air in the retort was soon expelled, and a continual but slow succession of oxi-hydrogen gas bubbles passed through the cup of mercury into which the end of the retort was dipped, which lasted during the whole continuance of the experiment. Every care had been taken to avoid atmospheric contact, and admittance of extraneous matter, and the retort itself had been previously washed with hot alcohol. This apparatus I placed on a shelf, in a dark subterranean cellar, and I examined it carefully every two or three days. After some weeks' action, gelatinous silica collected in some quantity around the end of the positive wire, but I discovered no sign of incipient animal formation, until, on the 140th day after the commencement of the experiment, I plainly distinguished *one* fat acarus actively crawling about

within the bulb of the retort, and above the fluid, on the upper part towards the neck. I held a lighted lamp behind the bulb with one hand, and examined every portion of it, by means of a common lens held in my other hand. When first I observed this little creature I thought it might be outside the bulb, and I passed my finger several times over it—but no, it was plainly and distinctly *within the bulb*, and was as active as possible. I never saw it again, and in spite of the closest examination and the continuance of the experiment for a *whole twelvemonth*, I never detected another. And now I found that, in spite of all my caution, I had committed a *great error* in the performance of this experiment, that is, I had omitted to insert within the bulb of the retort, a *resting place* for these acari, should any appear, for them to dwell upon. I have no doubt but that the one I saw, and perhaps others, had fallen down into the fluid and were destroyed. I ground this opinion upon two facts. First, I had observed in former experiments that if I let fall by means of a small camel's hair brush, one of those acari into the fluids, under which he had been born, he was immediately drowned—and secondly, my late friend Mr. Weekes, had made similar observations; moreover, it was not an easy matter to detect all the acari in the bulb of a retort which contained nearly a pint of fluid, by means of a lens with a short focal power. It is strange that in a solution *eminently caustic* and under an atmospere of *oxi-hydrogen gas*, one single acarus should have made his appearance.

"I shall now make mention of the last experiment I have made in which acari appeared, but which, I should observe, were quite unexpected by me. I had previously been trying some experiments upon sheep's wool, by passing the Electric current from a small sustaining battery through two porous pots, filled with salt and water, standing on a glass vessel side by side, which vessel was filled with the same fluid. These two porous pots were kept respectively positive and negative by platinum wires, connected with the opposite poles of the battery; and a small lock of wool was attached to the end of each wire. When the electric action began, the chlorine of the salt went of course to the positive pole, and the wool there suspended was impregnated with it, while at the same time the soda went to the negative pole, and similarly impregnated the wool in that porous pot. At the expiration of three weeks, I removed both locks of wool from their respective pots, and plunged the one just taken from the positive pot, and impregnated with chlorine into the negative pot, where it was, to my surprise, dissolved *in an instant*. I repeated this with fresh locks of wool, first moistening them in the positive pot, and after a short time, letting them fall into the nega-

tive, where they were dissolved but more slowly than at first. I continued this till the fluid in the negative pot would dissolve no more wool, after which I removed and filtered it. The solution was of a fine yellow colour, exactly similar in appearance to that of chloride of gold, and it was perfectly transparent. This solution I shall call B. It smelt rather strongly of chlorine, and with it I made the following experiment, with a view to decompose the solution, but not expecting animal life to appear during the process: I filled a tumbler with B, into which I immersed a small porous pot, filled with the same solution, and kept positive by a platinum wire connected with a small sustaining battery of three pairs of plates. Into this tumbler I let fall a piece of white quartz attached to a platinum wire, and connected with the negative pole of the same battery. This tumbler I placed in a tea saucer, and inverted a glass jar over the tumbler, which rested on the saucer, and the two wires of platinum which conducted the electric current passed between the bottom of the glass jar and the upper surface of the saucer. I made this arrangement merely to keep out the dust. This was set in action on June 10th, 1853. Some weeks afterwards, an assemblage of crystalline matter, some of which was perfectly transparent, and some white and opaque, formed upon that part of the negative platinum wire from which the quartz was suspended—not that portion which was immersed in B, but that part of the wire which was bent outside the tumbler to enable it to pass under the inverted glass jar in its passage to the negative pole. These crystals increased in size and number for some months, but are now somewhat diminished. It is difficult to describe their form properly; they are partly four-sided prisms, but curved in various directions, and they appear of small specific gravity. There is a constant faint smell of chlorine proceeding from the small aperture between the bottom of the inverted glass and the saucer. The crystals are discernible at some distance without the aid of a lens; in fact, some of them are occasionally half an inch in length, and occasionally much less, and they vary in size in proportion to the greater or less temperature of the room and the greater or less moisture which exists under the inverted glass jar, and which is occasioned by the slower or quicker evaporation of the fluid B in the tumbler. On the 27th of January, 1854, on examining this apparatus, I distinctly saw *one* perfect *acarus*, and some others in different stages, by means of a lens; but no movement was perceptible in the perfect insect. I took a drawing of these appearances. A week or two afterwards, I discovered another perfect *acarus*, but like the former, without motion. Both these acari, as well as others that afterwards appeared during this experiment, were on the interior of the inverted

glass jar which covered the tumbler, and were constantly in an atmosphere impregnated with chlorine, which was continually renewed by the electric action, which was always more or less causing its evolution from the fluid B. The limbs of the perfect *acari* were extended in a natural position, and they appeared in all respects like living insects, *but* without motion. Some of my friends who examined them with a lens, fancied they perceived a movement, but I believe this was a mistake, as they remained in their respective situations from the time I first saw them to the present date, February 5th, 1855. This has never occurred to me before. Whether the chlorine prevented their complete animation I cannot say. I must here observe that, although I have seen these acari during many previous experiments, I have never known them to make their appearance before, except during the warmer months of the year, say from April to October, both months inclusive. The least approach of frost has either prevented their birth or destroyed them when living; but on this occasion the result was entirely different, although the acari were precisely of the same kind as those I usually observed. There are at present three perfect acari, and some incipient ones, and they are perceptible by means of a common lens. This experiment is still continuing, and although the temperature of the situation in which the apparatus is placed, has been for some days past nearly down to the freezing point, not the least alteration is perceptible in the acari. I did expect during the warm months of last summer that they would have been in an active state, but this has not taken place."

(514) Among the most interesting of Mr. Crosse's experiments, are those in which he has imitated in a most extraordinary manner, "constant" and "intermittent" springs with the aid of the voltaic battery. The experiments were made in the following manner:—

1°. A common garden-pot full of moistened pipe-clay was placed in a basin full of water: a platinum wire connected with the negative extremity of a sulphate of copper battery of twelve pairs of plates, each two inches long by one inch wide, was placed three inches deep into the middle of the clay; and a second platinum wire connected with the positive pole, was plunged into the water in the basin, to the same depth. Within a fortnight *fissures* took place in the clay in contact with the negative wire; and in six or eight weeks, these fissures filled with water, which was drawn up two inches above the level of the water in the basin. A small pool of water was formed round the negative wire, which at last overflowed and trickled constantly into the basin below. Here, then, was a *constant electrical spring*.

2°. Here the experiment was varied; but the apparatus was precisely similar. In this, both wires were plunged three inches deep into the same pot of moist pipe-clay, at the opposite sides, but about three-quarters of an inch from each side. Within a fortnight, fissures took place at the negative, but none at the positive wire. In a month or six weeks more, these fissures filled with water, which overflowed, and after a day or two *ebbed*, and then again overflowed, and so on, being apparently acted on by change of weather. Mr. Crosse generally found the spring overflowing when the barometer was *very low*, and the reverse when it was *high*. Here then was an electrical *intermittent spring*,

(515) In subsequent experiments, Mr. Crosse found it better to employ porous earthen pots, open at the top and bottom, filled within an inch of the top with pipe-clay kneaded with water to the consistence of putty, and plunged into a basin—three platinum wires issuing from one stout wire connected with the negative extremity of the battery, being plunged three inches deep into the clay; and a group of six platinum wires issuing from one connected with the positive pole, being immersed to the same depth in the water. With this arrangement, if the battery is active, the water will rise in one night half an inch above the surface of the clay in the pot, the lip of which, together with the whole rim, to the depth of an inch, is glazed. Under the lip is placed a small shoot of sheet copper, to convey the water, as it falls drop by drop from the lip, to a graduated glass vessel. In one experiment, Mr. Crosse mixed dilute sulphuric acid with pipe-clay instead of distilled water. *Not one drop of water was raised upwards to the negative wire;* but the water in the basin, which was also acidulated with the same acid, was changed to a most beautiful *rose-red*. In a letter received from Mr. Crosse, addressed to the author, in the beginning of the year 1840, he says: "My two springs—the one *constant*, the other *intermittent*—are in as good action as ever. The intermittent one overflows generally when the barometer is somewhat below 29°; and is generally dry when the barometer is above that point. A row of open porous pitchers being filled with pipe-clay, all their lips turned the same way and all negatively electrified, may yield a succession of drops, which being collected in a shoot, may be used *to turn a small water-wheel*, thus producing perpetual motion; and *provided the power be found equivalent to produce such increased effect*, it may be applied in the most important ways. Also, the fissures formed in the clay at the negative pole, may be converted into *metallic lodes*, by mineralizing the water in the basin with metallic and other solutions: *this I have already done.*"

(516) The author's first repetition of these extraordinary experiments was not attended with successful results. By employing, however, a salt-and-water battery, of forty pairs, the observations of Mr. Crosse were verified in a most satisfactory manner.. After a continued action of about eight weeks, several ounces of water were drawn to the negative wire upwards of three inches above the level of the water in the exterior basin; and after the lapse of thirteen weeks there was a continual flow of water over the top and sides of the porous jar, amounting to upwards of an ounce daily. Common river-water was employed to fill the basin and to knead the pipe-clay. The odour of chlorine from the positive wire was very marked.

(517) The motion of fluids from the positive to the negative pole of the closed voltaic circuit has more recently been investigated by Wiedemann. (*Silliman's Journal*, Nov. 1852; *Phil. Mag.*, N. S., vol. iv. p. 546.) The apparatus employed by this physicist consisted of a porous earthenware cell, closed at the bottom, and terminated above by a glass bell, firmly cemented to the upper edge of the cylinder. Into the tubulure of the bell a vertical glass tube was fitted, from which a horizontal tube proceeded so as to permit the fluid raised to flow over into an appropriately-placed vessel; a wire, serving as the negative pole of a battery, passed down through the glass bell into the interior of the porous cylinder, where it terminated in a plate of platinum or copper. Outside the porous cylinder another plate of platinum was placed, and connected with the positive pole of the battery. The whole stood in a large glass vessel, which, as well as the interior porous cylinder, was filled with water. The intensity of the current was measured by a galvanometer. As soon as the circuit was closed, the liquid rose in the porous cylinder and flowed out from the horizontal tube into a weighed vessel. The results are summed up by Wiedemann as follows: 1°. The quantity of fluid which flows out in equal times is directly proportional to the strength of the current; 2°. Under otherwise equal conditions, the quantities of fluid flowing out, are independent of the magnitude of the conducting porous surface; 3°. The height to which a galvanic current causes a fluid to rise is directly proportional to the extent of the porous surface; 4°. The force with which an electric tension present upon both sides of a section of any given fluid, urges the fluid from the positive to the negative side, is equivalent to a hydostatic pressure which is directly proportional to that tension.

The above laws only hold good for fluids of the same nature. When different fluids are subjected to the action of the currents, the mechanical action is greatest upon those which oppose the greatest resistance to its passage.

(518). To return to the consideration of the secondary results of decomposition: it appears that there are two modes by which substances may be decomposed by the voltaic battery; 1st, by the direct force of the current; and 2ndly, by the action of bodies which that current may evolve. There are also two modes by which new compounds may be formed, *i. e.* by combination of evolving substances whilst in their *nascent* state directly with the matter of the electrodes; or else their combination with those bodies, which being contained in, or associated with, the body suffering decomposition, are necessarily present at the anode and cathode. When *aqueous* solutions of bodies are used, secondary results are exceedingly frequent. They are not, however, confined to aqueous solutions, or cases where water is present. Whenever hydrogen does *not* appear at the *cathode*, in an aqueous solution, it always indicates that a secondary action has taken place there.

(519) A series of admirable papers, on the electrolysis of secondary compounds, was published in the Philosophical Transactions by the late professor Daniell, of King's College. The primary object of these researches was, the determination of the relative proportions of the decompositions both of water and salt, when various saline solutions were subjected to the action of the voltaic current, and their relation to the amount of electrolytic force in action, with a view to increase our knowledge of the constitution of saline bodies in general.

(520) From an elaborate series of experiments on the sulphates of soda, potash, and ammonia, phosphate of soda, nitrate of potash, &c., it appeared, "that in the electrolysis of a solution of a neutral salt in water, a current which is just sufficient to separate single equivalents of oxygen and hydrogen from a mixture of sulphuric acid and water, will separate single equivalents of oxygen and hydrogen from the saline solution, while single equivalents of acid and alkali will make their appearance at the same time at the respective electrodes;" and further experiments showed, that whenever dilute sulphuric acid is used, there is a transfer of acid towards the *zincode* or anode, the quantity scarcely ever exceeding the proportion of one-fourth of an equivalent, as compared with the hydrogen evolved. Mr. Daniell thought possibly this might be owing to the acid being mechanically carried back to the platinode (cathode), as in all cases there is a mechanical connection of the liquid from the anode to the cathode; and this is greater in proportion to the inferiority of its conducting power. If, however, this deficiency of acid were owing to the mechanical *re-transfer*, mechanical means, such as increasing the number of diaphragms, would stop it: the proportion, however, was, even under these circumstances, still maintained. No difference

was observed, whether the oxygen was allowed to escape from a platinum anode, or whether it was absorbed by copper or zinc: the metals, of course, being dissolved in proportions equivalent to the hydrogen developed at the cathode. Solution of potash, baryta, or strontia, similarly treated, exhibited a transfer of about one-fourth of an equivalent towards the cathode.

(521) In order to remove the ambiguity which might thus possibly be conceived to arise from the employment of dilute sulphuric acid, as the measurer of the electrolytic force, the following arrangement was substituted for the voltameter: a green glass tube (into the bottom of which, as a cathode, was welded a weighed platinum wire) was filled with chloride of lead, maintained in a state of fusion by a spirit-lamp; the corresponding anode was made of plumbago. At the termination of the experiment, the tube was broken, the wire and adhering button of lead weighed; and the result showed, that "the same current which is just sufficient to resolve an equivalent of chloride of lead, which is a simple electrolyte unaffected by any associated composition, into its equivalent *iöns*, produces the apparent phenomena of the re-solution of water into its elements, and at the same time, of an equivalent of sulphate of soda into its proximate principles."

(522) Aqueous solutions of the chlorides were next tried, as the simple constitution of this class of salts promised to throw light upon the nature of the electrolysis of secondary compounds. A weighed plate of pure tin was made the anode of a double cell of peculiar construction, which was charged with a strong solution of chloride of sodium, and a tube of fused chloride of lead, as before, included in the circuit. Not a bubble of gas appeared on the tin electrode, and no smell of chlorine was perceptible; but hydrogen in equivalent proportion to the quantity of tin dissolved, was given off at the cathode; and the cell contained an equivalent proportion of free soda. One equivalent of lead was reduced in the voltameter tube. Muriate of ammonia treated in the same way, gave precisely similar results, proving it to be "an electrolyte," whose simple anion was chlorine and compound cathion nitrogen, with four equivalents of hydrogen. Its electrolytic symbol, therefore, instead of being $(Cl + H) + (N + 3\ H)$ is $Cl + (N + 4\ H)$, confirming, in a striking manner, the hypothesis of Berzelius, of the base $(N + 4\ H)$ called ammonium.

(523) In discussing the results of all these experiments, we must bear in mind the fundamental principle, "that the force which we have measured by its definite action at any one point of a circuit, cannot perform more than an equivalent proportion at any other

point of the same circuit." "The sum of the forces which held together any number of *iöns* in a compound electrolyte, could, moreover, only have been equal to the force which held together the elements of a single electrolyte, electrolyzed at the same moment in one circuit."

(524) In the electrolysis of the solution of sulphate of soda, and many of the other salts, water seemed to be electrolyzed; at the same time acid and alkali appeared in equivalent proportion with the oxygen and hydrogen at the respective electrodes. "We must conclude," says Mr. Daniell, "from the above-mentioned principle, that the only electrolyte which yielded, was the sulphate of soda, the iöns of which were not, however, the acid and alkali of the salt, but an anion, composed of an equivalent of sulphur and *four* equivalents of oxygen, and the metallic cathion, sodium. From the former, sulphuric acid was formed at the anode, by the secondary action and evolution of one equivalent of oxygen; and from the latter, soda at the cathode, by the secondary action of the metal and the evolution of an equivalent of hydrogen."

(525) To avoid circumlocution (but only when speaking of electrolytic decomposition), Mr. Daniell proposes to adopt the word iön, introduced by Dr. Faraday, as a general termination, to denote the compounds which in the electrolysis of a salt pass to the anode; and that they should be specifically distinguished by prefixing the name of the acid slightly modified, as is shown in the following table:—

Ordinary Chemical Formula.		Electrolytic Formula.
Sulphate of copper (S+3 O)+Cu+O)	=	S+4 O)+Cu oxysulphion of copper.
Sulphate of soda (S+3 O)+(Na+O)	=	(S+4 O)+Na oxysulphion of sodium.
Nitrate of potassa (N+5 O)+(Ka+O)	=	(N+6 O)+Ka oxynitrion of potassium.
Phosphate of soda (P+3½O)+(Na+O)	=	(P+4½O)+Na oxyphosph. of sodium.

(526) The following experiments, strongly favouring the above view, were made by Professor Daniell:—

A small glass bell, with an aperture at top, had its mouth closed, by tying a piece of membrane over it. It was half filled with a dilute solution of caustic potassa, and suspended in a glass vessel, containing a strong neutral solution of sulphate of copper, below the surface of which it just dipped. A platinum electrode, connected with the last zinc rod of a large constant battery of twenty cells, was placed in the solution of potassa; and another connected with the copper of the first cell was placed in the sulphate of copper immediately under the diaphragm which separated the two solutions. The circuit conducted very readily and the action was very energetic. Hydrogen was given off at the cathode in the solution of potassa, and oxygen at the anode in the sulphate of copper. A small quantity of

gas was also seen to rise from the surface of the diaphragm. In about ten minutes, the lower surface of the membrane was found beautifully coated with metallic copper, interspersed with oxide of copper of a black colour, and hydrated oxide of copper of a light blue. The explanation of these phenomena is this—In the experimental cell we have two electrolytes, separated by a membrane, through both of which the current must pass to complete the circuit. The sulphate of copper is resolved into its compound anion, sulphuric acid + oxygen (oxysulphion), and its simple cathion, copper. The oxygen of the former escapes at the zincode, but the copper in its passage to the platinode, is stopped at the surface of the second electrolyte, which, for the present, we may regard as water, improved in its conducting power by potassa. The metal here finds nothing by combining with which it can complete its course; but, being forced to stop, yields up its charge to the hydrogen of the second electrolyte, which passes on to the cathode, and is evolved. The corresponding oxygen stops also at the diaphragm, giving up its charge to the anion of the sulphate of copper. The copper and oxygen thus meeting at the intermediate point, partly enter into combination, and form the black oxide; but from the rapidity of the action, there is not time for the whole to combine, and a portion of the copper remains in a metallic state, and a portion of the gaseous oxygen escapes. The precipitation of blue hydrated oxide doubtless arose from the mixing of a small portion of the two solutions. Nitrate of silver, nitrate of lead, proto-sulphate of iron, sulphate of palladium, and proto-nitrate of mercury, were similarly treated, and afforded analogous results, somewhat modified by the nature of the metallic base. Sulphate of magnesia was subjected to the same process in hopes of finding magnesium, but magnesia alone was deposited.

(527) The theory of ammonium, as proposed by Berzelius, and the hypothesis of Davy, developing the general analogy of all salts, whether derived from oxyacids or hydracids, may, by this evidence, especially when taken in conjunction with the recent researches on the constitution of organic bodies, be considered as almost experimentally demonstrated.

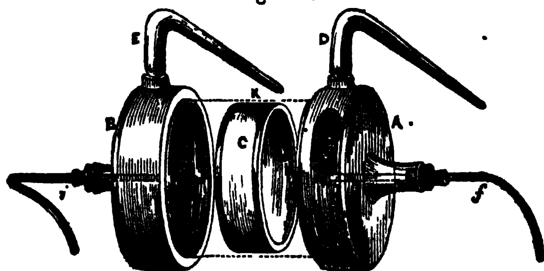
(528) The bisalts yield results which, at first sight, do not accord with the preceding deductions: a strong solution, for example, of pure crystallized bisulphate of potassa was made, and its neutralizing power carefully ascertained by the alkalimeter. Evaporation and ignition with carbonate of ammonia, gave the quantity of neutral sulphate yielded by a certain measure of the solution. An equal measure was then placed in each arm of the double diaphragm

cell,* and the current passed through till 70·8 cubic inches of mixed gases were collected: half the solutions from the anode and cathode were then separately neutralized, and half evaporated and ignited in the vapour of carbonate of ammonia. It was then found that the anode had gained eighteen grains, and the cathode lost nineteen of free acid: of potassa, the anode had lost 9·9 grains, and the cathode gained an equal quantity. Thus, though the solution conducted very well, not more than one-fifth of an equivalent of the potassa was transferred to the cathode, as compared with the hydrogen evolved; while *half* an equivalent of acid was transferred to the anode a *whole* equivalent of oxygen was evolved. On this experiment Mr. Daniell remarks:—

"I think we cannot hesitate to admit, that in this case the current divided itself between two electrolytes, that a part was conducted by the neutral sulphate of potassa, and a larger part by the sulphuric acid and water. It is a well known fact, that the voltaic current will divide itself between two or more metallic conductors in inverse proportion to the resistance which each may offer to its course: and that it does not in such cases choose *alone* the path of *least* resistance. Analogy would lead me to expect a similar division of a current between two electrolytes; but I am not aware whether such a division has ever before been pointed out."

* This apparatus, which was found by Daniel very useful in his experiments on the electrolysis of secondary compounds, is shown in Fig. 210, and is thus described by its author (*Introduction to Chemical Philosophy*, 2nd edit., p 533):—

Fig. 210.



A and B are the two halves of a stout glass cylinder, accurately ground so as to fit into two half cylinders, which, when adjusted, cover it entirely. The two rims of the ring are each cut down to a shoulder, to admit of a thin piece of bladder being tied over them to form a kind of drum. At K is a small hole to admit of the cavity being filled with a liquid. D and E are two stout bent tubes, fitted to the two half cylinders, for collecting the gases evolved in the experiments: *g* and *h* are two circular platinum electrodes, connected with the battery by the wires *i f*. The apparatus, when adjusted, forms three compartments, each of which may be filled with the same or a different liquid, and the whole may be supported on a wooden frame.

(529) These considerations enable us to explain the apparent anomalies in the electrolysis of diluted sulphuric acid and alkaline solutions alluded to. The results are explained by supposing that the solution is a mixture of two electrolytes: with sulphuric acid, they are H + (S + 4 O) oxysulphion of hydrogen; (H + O) water. The current so divides itself, that three equivalents of water are decomposed, and one equivalent of oxysulphion of hydrogen. Analagous changes occur with the alkaline solutions, the alkaline metal passing as usual to the cathode.

According to Professor Daniell's view of Faraday's beautiful experiments with sulphate of magnesia (481), the first electrolyte was resolved into a compound anion, sulphuric acid + oxygen, which passed to the anode, and the simple cathion magnesium, which on its passage to the cathode was stopped at the surface of the water from not finding any iön, by temporarily combining with which, it could be further transferred according to the laws of electrolysis. At this point, therefore, it gave up its charge to the hydrogen of the water, which passed in the usual manner to the cathode, and the circuit was completed by the decomposition of this second electrolyte. The corresponding oxygen, of course, met the magnesium at the point where it was arrested in its progress, and, combining with it, magnesia was precipitated. This combination of the oxygen and metal is looked upon by Professor Daniell as a *secondary* result, due to the local affinity of the elements thus brought into juxta-position, and in no way connected with the primary phenomena of the current, which would have completed its course, whether this combination had taken place or not; *i. e.* whether magnesium and oxygen had been separately evolved, or whether magnesia had been formed by the combination of the two. It also seemed probable that, although in the very slow action of this experiment this combination invariably took place, by varying the experiment so as to evolve metals possessing different degrees of affinity for oxygen, and particularly by shortening the time in which the evolution might take place, instances might be found of some portion of the metal escaping this combination, which would thus afford the most incontrovertible proof of the point to be established. Professor Daniell was thus led to the experiment above detailed.

(530) *Voltaic reduction of ores.* M.M. Dechaud and Gaultier de Claubry in France, and Messrs. Napier, Ritchie, and Crosse in this country, have made metallurgical applications of Becquerel's discovery of the chemical actions determined under the influences of feeble electric currents, and the latter gentlemen have patented their processes. The following are the data on which the apparatus of the

French chemists is based: (*Comptes Rendus*, June 2, 1843.) If we place upon each other two solutions, the one of sulphate of copper, and the other of sulphate of iron, the former being the densest, place in the sulphate of copper a plate of metal forming the cathode, and in the sulphate of iron a piece of cast iron, and unite the two metals by a conductor, the precipitation of copper immediately commences, and is completed in a longer or shorter space of time, depending on the temperature, or the concentration of the liquids, and on the extent of the metal surfaces. In applying this process to metallurgy, a wooden box lined with lead, or protected by proper varnish, contains the sulphate of iron; an opening above introduces the liquid at a given degree of density, and another below permits the concentrated solution to pass away. Into this are immersed cases formed of a frame the ends and bottom of which are of sheet lead, and the lateral sides of which are furnished with a sheet of pasteboard; a lower opening gives entrance to the saturated solution of sulphate of copper, and another opening higher up, gives exit to the exhausted sulphate. In each case is placed a sheet of lead, between them, and also on the outside of the two extreme cases are plates of cast iron; distinct conductors affixed to each plate make it communicate with a common conductor placed outside the apparatus. The two solutions are supplied from appropriate reservoirs. The density of the liquids is regulated once for all, and the apparatus goes on working for months together without requiring any kind of care; at a temperature of 66° Fahr. 1·19 square yards of surface receives 2·2 lbs. of copper in twenty-four hours. The metal is pure and constant in its physical character. The Committee appointed by the French Academy, consisting of M.M. Berthier, Dumas, and Becquerel, reported favourably upon this process, remarking, however, that it required that the ores to be transformed should be converted entirely into sulphate, in which the whole industrial question consists.

(531) The following is an extract from Mr. Ritchie's patent: (sealed October 13th, 1844, enrolled April 10th, 1845; *Repertory of Patent Inventions*, June, 1845.) "The solution of the calcined ore is placed in a rectangular vessel of any required length; on the upper surface is placed a solution of sulphate of iron to be used as the exciting solution; thus prepared, the generating plate (a surface of cast iron), is introduced, which is connected by copper or other conducting material with a plate of lead or suitable metal, having an equal extent of surface with the cast iron; and these plates or surfaces so connected, being introduced into solutions in the vessels, the copper in the solution will be quickly deposited. It will be found that in the course of working, the solution of sulphate of copper, which at start-

ing is a saturated solution, will become at its upper part lighter than lower down, and the patentee prefers that it should be drawn off when it has lost half its copper, and it is evident that the solution of sulphate of iron, which at starting is made by mixing two parts of water with one of saturated solution, will become, at its lower part, of greater specific gravity than the upper part; and he prefers to draw off the solution when it becomes as dense as the weaker solution which is being drawn off."

(532) Mr. Napier's process is thus specified: (*Repertory of Patent Inventions*, July, 1845.) "I take a large crucible, or other convenient vessel, made of an electro-conducting material; those I have used being plumbago (common black lead); the inside of this vessel I line all round with a lute of clay, except the bottom, which I leave uncovered; the luting should be very thin, and laid on in two or three coats, drying slowly between each, so as to prevent cracking. When the vessel is sufficiently luted and dried, I put therein (with the usual fluxes) the regulus or calcined ore, which, when sulphurets are used, should have been well roasted, so as to drive off as much as possible of the sulphuret; I then place the vessel with its contents in an ordinary air-furnace, keeping up the heat until the mass is in a state of fusion. In the meantime, I have prepared an ordinary voltaic battery of copper and amalgamated zinc charged with acidulated water, one part sulphuric acid, twenty-five parts water. To the positive wire of this battery I attach an iron rod, having rivetted at right angles to its extremity a flat disc of iron, the disc being a little smaller than the inner circumference of the crucible; to the negative wire of the battery, I attach a simple rod or bar of iron. The matter in the crucible being in a state of fusion and well fluxed, I place the above-mentioned disc of iron, which will now form the positive pole of the battery, on the surface of the fused mass, and keep the rod which is connected with the negative pole in contact with the outside of the crucible, the bottom of which thus forms the negative pole. The fused matter now forms a portion of the electric circuit, and the heat being kept up, the metal is gradually reduced and deposited at the bottom of the crucible. The proportions I have found suitable are as follows: For every hundred weight of regulus of 30 per cent. of metal, I employ a battery of five pairs of plates, the size of the zinc plates being three feet square, and the copper doubled round the zinc in the usual way. The size of the pole should be smaller than the zinc plates. With apparatus of these proportions, the time for extracting the metal varies from one to two hours. The metal so extracted may be refined when necessary in the usual way."

(533) In the specification of his patent, Mr. Crosse describes his

invention as follows: (*Repert. Pat. Invent. N.S.* 21, p. 235.) "I cause the ore to be calcined, and then reduced to powder, and I employ an apparatus, consisting of a tub or vessel, which I prefer to be of wood or earthenware; at the bottom of this vessel I apply a frame of strong platinum wire, of the dimensions of the interior of the vessel; the frame has formed on it reticulate platinum wire-work or netting, with meshes of about an inch each way. The frame and netting is lowered down on, and covers the ore placed on, the bottom of the vessel; a platinum wire is connected to the frame, and also with the positive pole of a Daniell's battery. The connecting platinum wire is covered with gutta percha when working with cold liquid, and with other non-conductor when the liquid is heated, from the point where it is connected with the frame up to a point above the vessel, so that the fluid within may not come in contact with the wire. The battery which I have employed when acting with a vessel containing about 250 or 300 quarts of diluted acid, consists of twenty pairs of plates, each in a gallon glass vessel, which I fill with a saturated solution of sulphate of copper, and add one twentieth to one-tenth of sulphuric acid. To the negative pole of the battery I affix a copper wire, and to the other end of such wire I (by three or more smaller ones) suspend a basin of wood which is lined on the inside with sheet copper, and I cover this lining with a cover of copper-wire netting, which consists of about one-inch meshes; the copper lining is in contact with the suspending wires. Into the vessel I put about 230 to 235 quarts of diluted sulphuric acid, using about five quarts of sulphuric acid of commerce to 230 quarts of water; into this liquid I introduce about 15lb. of the powder of calcined ore, stirring the fluid as the powder descends.

"I have found it desirable that the ores should remain in the dilute acid some three or four days before subjecting the same to electric currents, stirring from time to time; after which, and immediately after stirring, I introduce the frame of platinum wire, and then the battery being charged, the process of separating the copper will immediately go on, and the copper will be received into the basin in the form of a powder; the process of separating all the copper requires some days, and I have not found that the acid solution requires to be added to, during the process; the other metals separated from the copper will be in the sediment at the bottom of the vessel, and when the process is completed, or judged to be completed, the liquid is run off with the remaining or sediment matter at the bottom of the vessel, and the vessel is again to be charged. If, on testing the deposited matters, after they have been run off and allowed to subside, they indicate a material quantity of copper, I again calcine

them and add them to calcined ores, or a quantity of subsided matter in the vessel may, before being run off from the bottom of the vessel, be tested to ascertain whether it is desirable to carry on the process further thereon. The dilute acid run off from the subsided matters may be used again. I have found it desirable to heat the liquid during the process as much as conveniently may be done, even up to boiling, and this I have done when using earthenware vessels by means of a sand-bath."

(534) Mr. Crosse has also patented a process "for extracting or separating impurities or matters from fermentable, fermented, and other liquids, by electric action." (*Rep. Pat. Inven. N.S.* 10, 1847, p. 231.) Supposing the liquid to be wine, or cyder, or other fermentable liquid, he immerses in the cask two porous tubes, the upper part of which comes above the liquid; into one tube he places a cylinder of zinc, and in the other a cylinder or coil of iron, connecting the two together by a metallic strip. The tubes are then filled with water; an electric action is set up in the liquid which is continued till the necessary degree of attenuation has been obtained, when the liquid is removed, casked off, and closed up. He states that this process materially improves the character of the liquid, and tends to prevent its becoming acid. In applying the process to the purification of sea water, he first causes the water to be distilled once, and then operates by electric action as above described; the impurities of the water are precipitated, and gaseous matter is evolved, and any acid and alkaline properties go to the porous tubes; the water is thus purified. The same gentleman has likewise patented a process for applying electric or galvanic effects in the pots or vessels in which hides or skins are under process of tanning, for an account of which see *Repert. Pat. Invent. N.S.* 15, 1850, p. 35.

(535) *Electro-metallurgy.*—In our historical account of the sulphate of copper battery of Daniell it was stated, that on completing the circuit, the electrical current passes freely through the metallic solution; that no hydrogen makes its appearance on the conducting plate, but that a beautiful pink coating of pure copper is deposited on it, and thus perpetually renews its surface. In the discovery of this battery, then, we find the origin of electro-metallurgy; for it appears that in his earlier experiments it was noticed by Mr. Daniell that on removing a piece of the reduced copper from a platinum electrode, scratches on the latter were copied with accuracy on the copper, and Mr. De la Rue, later, in a paper in the Phil. Mag.,* detailing some experiments with a voltaic battery of ordinary construction, charged with sulphate of copper, made the observation

* Vol. ix. p. 484.

that "the copper plate is covered with a coating of metallic copper, which is continually being deposited;" and he proceeds to remark, "so perfect is the sheet of copper thus formed, that on being stripped off it has the polish and even a counterpart of every scratch of the plate on which it is deposited." On reading this passage at the present time, when the art of electro-metallurgy is so extensively practised, we can hardly resist a feeling of surprise that the application of the *facts* discovered by Daniell and De la Rue did not occur to either of these gentlemen. They were, however, probably too intent on the battery itself to attend to any collateral circumstances, and it was left for Jacobi in Russia, and Spencer in this country, to do so. The process of the former distinguished philosopher was called "*Galvanoplastic;*" that of Mr. Spencer, "*Electrography.*" And though it is quite certain that the discovery was made by each, independent of the other, the priority must be given to Jacobi, who states in the preface of his "Galvanoplastic,"* that it was in the month of February, 1837, while prosecuting his galvanic investigations, that he discovered a striking phenomenon which presented itself in his experiments, and furnished him with perfectly novel views; and Mr. Spencer, in his pamphlet,† informs us that his first results were obtained in 1838.

(536) The description of an original experiment is generally interesting; it is always so when connected with a subject of much practical importance. We shall therefore insert Mr. Spencer's account of his first successful experiment in electrography:‡ "I selected a very prominent copper medal. It was placed in a voltaic circuit, and a surface of copper deposited on one of its sides to about the thickness of a shilling. I then proceeded to get the deposition off. In this I experienced some difficulty, but ultimately succeeded. On examination with a lens, every line was as perfect as the coin was from which it was taken. I was then induced to use the same piece again, and let it remain a much longer time in action, that I might have a thicker and more substantial mould, in order to test fairly the strength of the metal. It was accordingly again put in action, and let remain until it had acquired a much thicker coat of the metallic deposition; but on attempting to remove it from the medal, I found I was unable. It had apparently completely adhered to it. I had often practised, with some degree of success, a method of preventing the oxidation of polished steel, by slightly heating it until it would melt fine bees' wax: it was then wiped apparently completely off, but the pores or surfaces of the metal became impregnated with the

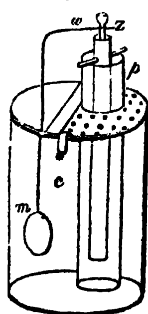
* Translated from the German edition, by Wm. Sturgeon.

† Griffin's Scientific Miscellany, No. iv. p. 33. ‡ See his Pamph. p. 33.

wax. I thought of this method, and applied it to a copper coin. I first heated it, applied wax, and then wiped it off so completely that the sharpness of the coin was not at all interfered with. I proceeded as before, and deposited a thick coating of copper on its surface. Being desirous to take it off, I applied the heat of a spirit-lamp to the back, when a sharp crackling noise took place, and I had the satisfaction of perceiving that the coin was completely loosened. In short, I had a most complete and perfect copper mould of one side of a halfpenny."

(537) The first kind of apparatus employed by Mr. Spencer was simply a common tumbler to hold the copper solution, and a gas-glass having one end closed with brown paper, or plaster of Paris, to contain the saline solution; the coin to be copied, and a piece of zinc of equal size, were attached to the extremities of a piece of copper wire. The gas-glass being fixed in the axis of the tumbler, the zinc was placed in it, and the copper wire bent in such a manner as to bring the coin immediately under it in the copper solution. The battery process is subsequently described by Mr. Spencer, but he gives no method of depositing copper on any surface but a metallic one. In Jacobi's pamphlet, however, which was published at St. Petersburg in March, 1840, the use of plumbago, for giving a conducting surface to non-metallic substances, and so enabling them to answer all the purposes of metallic originals, is distinctly alluded to. It appears, however, that Mr. Murray has the merit of having introduced this discovery into this country; and the Society of Arts have recorded their sense of its value by presenting this gentleman with a silver medal. The employment of the battery was first suggested by Mr. Mason, who, by connecting a piece of copper with the anode in a second cell, the object to be copied being connected with the cathode, showed that the quality of the copper was much better than when reduced in the single cell apparatus, besides the great advantage that was gained by the unlimited number of operations that may be going on at the same time.

Fig. 211.

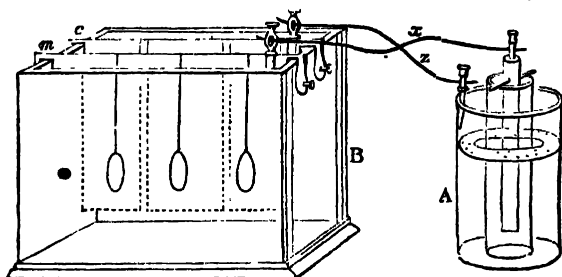


(538) Fig. 211 represents the single cell apparatus. *Z* is a rod of amalgamated zinc; *m*, the mould; *w*, the wire joining them; *c*, the copper solution; *p*, a tube of porous earthenware, containing a solution of acid and water. To put this in action, pour in the copper solution, fill the tube with the acid water, and place it as shown in the figure. *Last* of all put in the bent wire, having the zinc at one end, and the mould at the other. It is essential that the copper solution be kept saturated, or nearly so; with which view the

perforated shelf must be kept well furnished with crystals of sulphate of copper. The mould must not be too small in proportion to the size of the zinc, and the concentrated part of the solution must not be allowed to remain at the bottom, or the copy will be irregular in thickness.

Fig. 212 represents the battery apparatus. A is a cell of Daniell's battery (or Smee's may be used); B is the decomposition cell, filled

Fig. 212.



with the dilute acid solution of sulphate of copper; *c*, the sheet of copper, to furnish a supply; *m*, the moulds to receive the deposit. To charge this, pour in the several solutions, and connect the wire *z* with the copper sheet and the copper of the battery. *Last* of all, attach the wire *x* to the zinc and the moulds. The charging liquid is a mixture of one part *sulphuric acid*, two parts *saturated* solution of sulphate of copper, and eight parts water. When the circuit is complete, the copper from the solution is transferred to the mould, and the copper sheet is dissolved, being converted, with the sulphuric acid, into sulphate of copper, thus keeping up the strength of the solution. Rather a longer time is required by this method than with the single cell, but two days will produce a medal of very good substance, firm and *pliable:* the time required, however, for these experiments, depends much on the *temperature.* If the solutions are kept boiling, a medal may be made in a few hours: in severe weather, the action of the battery almost ceases, and it is necessary to carry on the operations before a good fire.

Fig. 213.

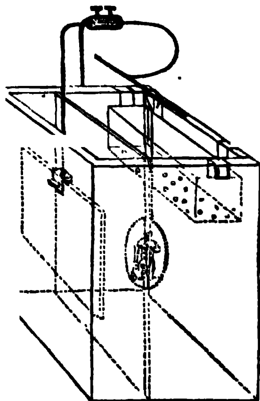
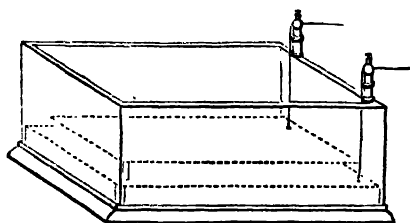


Fig. 213 represents a form of electrotype trough, to be used without acid or mercury. It consists of a wooden box, well varnished in the interior, and divided

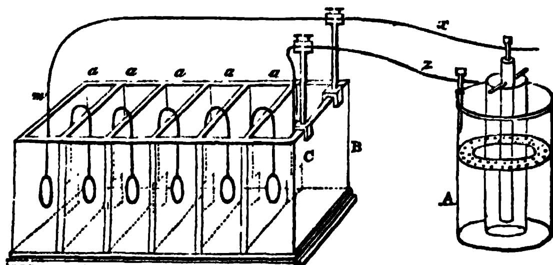
into two unequal cells by a partition of porous wood. The larger cell is filled with a saturated solution of sulphate of copper; the smaller, with a half saturated solution of muriate of ammonia. In the former is a shelf, containing a supply of crystals. The zinc plates employed for this are *pure*. This is a matter of some importance, because there then is no need of amalgamation to destroy local action; and the instant the circuit is interrupted all action ceases. Ordinary zinc may be used, but less power is obtained. This form of apparatus may be used as a single cell, or with a decomposition trough. It must not be expected that the action will be equally quick with that resulting from the addition of acid, but it will be sure—perhaps more so than in the other instance; for it must be borne in mind, that in "electrotype manipulation the failure in nine cases out of ten results from the power of the battery being too strong, and not from its being too weak."—*Walker*.

Fig. 214.



(539) For taking off copper plates, the apparatus shown in Fig. 214 may be employed; and by adopting the arrangement shown in Fig. 215, six electrotypes may be taken off at the same time. A is the battery, B the trough, *z* the wire connecting the copper plate C with the copper cell of the battery, *x* the wire connecting the mould with the zinc of the battery, *a a a a a* five bent wires, each having a mould at one end, and a piece of copper at the other. The following directions are given by Mr. Walker for charging this trough. "Connect the

Fig. 215.



copper plate C with the battery: place a *wire* with its extreme ends dipping in the extreme cells of the trough; then, having previously connected the zinc and mould with the wire *x*, place the zinc in the porous cell, and the mould in its place at *m*; in about two minutes

it will be covered with copper. After this there is no fear of chemical action; then remove the end of the copper wire from the cell containing *m*, and place it in the next cell; complete the circuit with the bent wire *a*, having a mould at one end, and a sheet of copper at the other. After waiting two minutes for a deposit of copper, remove the end of the wire one cell further forward; and so continue, till the six moulds are placed in." The advantage, in point of economy, from using this form of decomposition trough, is at once apparent, when it is remembered that for every *ounce* of copper released from the solution in the generating cell, an ounce will be deposited on each mould, and about *an ounce* of zinc will be consumed in effecting this. Whether, therefore, one, or six, or even twenty moulds be placed in series, the *same quantity* of zinc will be required; and hence, an ounce of zinc may be made to furnish Electricity enough to produce, according to the will of the experimenter, one, or six, or more medals, each weighing an ounce. This follows immediately from the laws of definite electro-chemical action, developed by Faraday.

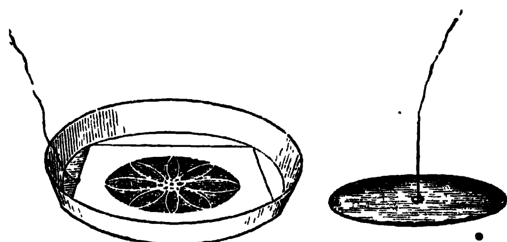
(540) It may perhaps be almost unnecessary to remark that these metallic deposits are all *secondary* results of the voltaic battery. Water is the compound electrolyzed, and hydrogen the element disengaged at the cathode by the *direct* action of the current; but this element re-acts on the metallic solution, combining with its oxygen, and setting free the metal. Oxygen is also disengaged at the anode, but it is not set free, because it immediately meets with an element with which it can combine. So also in the processes for gilding and silvering, where *cyanides* of gold and silver are employed, the anodes being pure gold and pure silver. Cyanogen is the substance disengaged at the anode, and though itself a compound body, it is capable of combining with these noble metals when presented to them in its nascent state, and thus a quantity of metallic salt is retained in the solution equivalent to that which is decomposed.

(541) The preparation of the argento and auro-cyanide solutions in Elkington's large electro-metallurgical establishment is as follows: (*Napier.*) The best yellow prussiate of potash is well dried upon an iron plate, and then reduced to fine powder: carbonate of potash is similarly treated; eight parts of the former are well mixed with three of the latter. They are placed in a hot iron pot on the fire, and when melted, are covered and allowed to remain for about half an hour; the contents are then poured upon an iron plate, and form the simple cyanide of potassium. Nitrate of silver is next prepared and precipitated in the form of cyanide of silver by the careful addition of cyanide of potassium; it is well washed, and is now dissolved in cyanide of potassium to form the argento-cyanide. The

articles to be plated are first boiled in potash, then scoured with fine sand, and afterwards passed through nitric acid, and washed in boiling water. After a few seconds of electric action, they are brushed with a scratch brush to perfect the cleansing, and are then replaced to complete the plating, which process is accomplished in five or six hours; after which they are burnished. The auro-cyanide is not so easy of preparation. The plan formerly adopted of dissolving oxide of gold in cyanide of potassium is not adopted now. The solution is prepared by electrolysis: a porous tube containing cyanide of potassium in solution, is placed within a vessel of a similar solution; within the tube is a gold anode, within the vessel the cathode is placed; the liquid is electrolyzed, and the gold being dissolved, forms the gilding solution, which is removed from the porous tube for use; when sufficiently saturated, the liquid in the outer tube becomes a solution of potash. Electro-gilding is conducted with a solution at a temperature of 123° Fahr. The mode of obtaining solid silver copies of articles much undercut is as follows: To twelve parts of glue, carefully melted, are added three parts of treacle, and the whole is well incorporated; an elastic mould of the object is taken; the object being removed, a cast is made in the mould with a composition consisting of three pounds of tallow and wax and half a pound of resin. To this composition the power of reducing silver is given by mixing with it some phosphorus dissolved in bisulphuret of carbon. It is removed from the mould and dipped into nitrate of silver, and to ensure success, is then dipped into chloride of gold, by which its surface becomes covered with a metallic fibre. A certain substance of copper is now deposited upon it, and the composition is melted away. The inside of the copper mould is well cleaned, and its outside is protected with a mixture of tallow and pitch, when it is placed in the silver solution, and subjected to the action of the voltaic current until a sufficient substance of metal is deposited. The copper is now dissolved off with a solution of perchloride of iron.

(542) *Metallo-chromes.*—When acetate of lead is electrolyzed, under peculiar circumstances, it gives rise to secondary results of a particularly beautiful character: peroxide of lead is deposited at the anode, and by carefully regulating the thickness of this compound, a series of most magnificent colours may be produced on a plate of highly-polished steel. The process recommended by Mr. Gassiot, to form these *metallo-chromes*, is this: Place the polished steel plate in a glass basin, containing a clear solution of acetate of lead, and over it a piece of card with some regular device cut out, as shown in Fig. 216. A small rim of wood should be placed over the card, and on that a circular copper disc. On contact being made from 5° to 20°, with

Fig. 216.



two or three cells of a small constant battery, the steel plate being connected with the copper or silver, and the copper disc with the zinc, the deposit will be effected, and a series of exquisite colours will appear on the steel plate. These colours are not films of oxygen and acid, as some have imagined, but lead, in a high state of oxidation, thrown down on the surface of the steel, and the varied tints are occasioned by the varying thickness of the precipitable film, the light being reflected through them from the polished metallic surface below. By reflected light, every prismatic colour is seen; and by transmitting light, a series of prismatic colours complementary to the first series will appear, occupying the place of the former series. The colours are seen in the greatest perfection by placing the plate before a window, and inclining a sheet of white paper at an angle of 45° over it.

(543) *Ozone.*—Allusion was made in a former chapter (236) to a peculiar odorous principle, developed during the passage of a torrent of dense sparks of Electricity, between two metallic plates enclosed in a cylinder of glass. Every person who has been in the habit of experimenting with a large electrical machine, must have remarked this peculiar odour, particularly during the escape of positive Electricity from a point; the same is perceptible when lightning has struck an object; and when a discharge from a large jar or battery is sent through several sheets of paper, it is exceedingly strong. M. Schoenbein appears to have been the first to notice that it accompanies the electrolyzation of water: and the phenomena connected with its development have been minutely investigated by him, and by other Electricians.

(544) The facts first ascertained by Schoenbein were these: (*Rep. Brit. Assoc.* 1846.) 1°. The odoriferous principle developed during the electrolysis of water is only disengaged at the positive pole, and may be preserved for an unlimited time in well closed bottles 2°. It is destroyed by heat and by a number of ozidizable bodies 3°. The electrical brush has the same odour and properties, and both polarize negatively gold and platinum. The principle is developed only in

very minute quantities by electrical action, but by enclosing a piece of phosphorus in atmospheric air at 60°, it is produced abundantly; but the air must not be *dry*, neither must there be present any oxidizable substances. It is not produced in pure oxygen. The peculiar smell is always produced in an atmosphere in which phosphorus emits light.

(545) The following are the properties of *ozone:* It bleaches without reddening blue litmus paper; it decolorizes solution of indigo; it is instantly destroyed by most metals, even silver is converted into oxide. Phosphorus is oxidized by it into phosphoric acid, iodine into iodic acid, and sulphurous and nitrous acids into sulphuric and nitric; it decomposes, and is destroyed by, sulphuretted, seleniuretted, and carburetted hydrogen; it converts many protoxides into peroxides; it instantly liberates *iodine* from iodide of potassium; hence, iodized starch-paper is the best test for it; it liberates *bromine* from bromide of potassium, converts yellow into red prussiate of potash, and many sulphurets into sulphates; it is instantly destroyed by most animal and vegetable substances. Air strongly charged with ozone has a smell very similar to that of chlorine, bromine, and iodine, and when much diluted with air, the odour cannot be distinguished from that developed near points of electrical emission. *Ozonized air* is poisonous, acting on the animal system like chlorine. A mouse speedily perishes when immersed in a jar impregnated with it. The oxygen from electrolyzed water is not ozonized if the water is hot, nor if the electrodes are of oxidizable metals, nor if there be any oxidizable substance present. The electrical brush does not develop the odour if the point from which it is passing is heated not quite red hot, but when the point is cooled the odour appears, and with it all the properties of ozone, *viz.*, bleaching action on iodine starched-paper, electro negative polarization of platinum, &c., &c. The odoriferous principle of the electrical brush is identical with that disengaged at the positive electrode, and with the electro-negative principle resulting from the action of phosphorus on moist atmospheric air. No ozone is disengaged when the water electrolyzed is thoroughly deprived of atmospheric air; but no ozone is formed by phosphorus in dry air, nor in pure oxygen; yet nitrogen is not absolutely necessary, as that gas may be replaced by carbonic acid, or by hydrogen, without stopping the generation of ozone.

The luminosity of phosphorus, in ordinary atmospheric air, is occasioned by the ozonization of that substance; phosphorus possesses the peculiar property of determining the formation of ozone out of oxygen and aqueous vapour, and of subsequently decomposing it. Phosphorus oxidizes in atmospheric air by the agency of ozone, and

this explains the reason why phosphorus does not shine in air containing oxidizable substances, such as nitrous and sulphurous acids, sulphuretted hydrogen, &c., bodies which take up or destroy ozone.

(546) From his first researches, Schoenbein came to the conclusion that ozone is a compound of oxygen and water, an opinion likewise entertained, as we shall see presently, by the latest writer on the subject, M. Baumert; but its properties differ from those of Thenard's peroxide of hydrogen, with which, however, Schoenbein thought it probable that it might turn out to be isomeric. Ozone, doubtless, plays an important part in the atmosphere. Iodized starch-paste is decomposed, and becomes blue by exposure to the *open* air, but not when enclosed in bottles of air, oxygen, or carbonic acid. The principle which causes this elimination of iodine is ozone set free, and continually developed in the atmosphere by the disturbance of the natural electrical equilibrium, and by atmospheric Electricity, and this principle would probably accumulate to an injurious extent but for its continued removal by oxidizable substances, organic matters, &c.; and the oxidizing power of atmospheric air, so much greater than that of pure oxygen, is, in a great measure, to be attributed to the action of ozone. *Dry*, that is, unozonized atmospheric air does not, at common temperatures, act on the most oxidizable of metals, neither is there any reaction between dry organic substances and anhydrous atmospheric air. Schoenbein suggests that there may be other substances, which, like phosphorus, have the (catalytic ?) power of generating ozone—*shining* wood, for instance, and other organic substances that undergo slow oxidation in the air. The phosphorescence of the sea, probably originating in the oxidation of organic matter, the remains of countless numbers of animals, dying daily in the depths of the ocean, may probably also be referred to a similar catalytic generation of ozone. He even suggests that the glow-worm may be another instance of the same kind of action.

(547) An investigation into the nature of ozone was undertaken by MM. Fremy and Becquerel. (*Comp. Rend., March*, 1852.) They found it impossible to procure this substance in quantities sufficient for their experiments by the electrolysis of water, neither could the voltaic arc be employed, as the intense heat destroyed the ozone as fast as it was produced. They found, however, that the secondary inductive spark, obtained by Rhumkorff's magnificent apparatus, (which we shall hereafter describe,) acts like the common electric spark, and with this they made the following remarkable experiments:—

1°. Pure oxygen enclosed in glass tubes, together with a band of starched and iodized paper was electrified by means of sparks striking

the *outside* of the tube; the paper became blue, not in consequence of the decomposition of the iodide, because the same effect did not take place in an atmosphere of hydrogen, but it depended on the electrization of the oxygen, and that without the intervention of metallic particles, there being no metallic wires used in the experiment. The gas also acquired a peculiar odour; it lost both its odour and its chemical activity by exposure to iodide of potassium, but regained both when again electrified; and this experiment could be repeated indefinitely on the same quantity of gas. It is evident that the oxidizing power of electrified oxygen is not due to the presence of a foreign body contained in the gas. 2°. By continuing to electrify oxygen, the modification, as judged of by its absorbability, by alkaline iodide, increased for some time, but it afterwards appeared to diminish. the spark probably destroying that, which at first it produced. By sending sparks into small eudiometry-tubes, filled with moist oxygen, and placed either over mercury or iodide of potassium, or containing in their interior a moistened silver leaf, the gas became absorbed in a regular manner, and in this way they sometimes obtained a complete absorption. Some iodide of potassium and moistened silver were inserted in tubes with pure oxygen, and then the tubes were closed; they were electrified for several days; the sparks grew gradually paler and paler, and at last almost disappeared. On opening the tubes under water, the liquid rushed in, and filled them entirely, thus showing that a complete vacuum had been obtained, and that the oxygen had become completely absorbable without heat, by the silver and iodide of potassium.

These facts confirm the later researches of Marignac, De la Rive, &c., and show that Electricity, acting upon oxygen, developes peculiar properties in it, and MM. Fremy and Becquerel propose to banish the name of *ozone*, which expresses the idea of the transformation of the oxygen into a new body, and to call the oxygen in which this remarkable chemical activity is awakened simply "*electrified oxygen.*"

(548) To this name Schoenbein objects (*Jour. für prakt. Chem.* 1852), because oxygen can be ozonized much more effectually by phosphorus than by Electricity, and in the modification of oxygen by phosphorus, &c., there is no disengagement of Electricity. According to his observations, 1000 parts of phosphorus can convert 1720 parts of oxygen into ozone with tolerable rapidity.

The "ozonization" of oxygen by electric sparks in closed tubes, in the experiments of Fremy and Becquerel, Schoenbein believes to be the result of an electrical induction in the oxygen from the exterior, and through the glass; the same takes place, on the large scale, on the occasion of every flash of lightning: houses are sometimes filled with

the odour of ozone, at considerable distances from the buildings that are struck.

De la Rive explains the ozonization of oxygen by supposing that, in ordinary oxygen, the atoms are not separate, but combined in groups, forming compound molecules, and that phosphorus, Electricity, &c., possess the power of breaking up these molecules into separate atoms, whereby its chemical activity is increased, and it is now rendered capable of oxidizing bodies on which before, it exerted no action. In many of its combinations, however, oxygen seems to exert the eminently oxidizing power of ozone; as, for instance, in *peroxide of lead, peroxide of nitrogen, &c.*, and Schoenbein proposes to call these substances "ozonized" oxide of lead $PbO+O$; "ozonized" nitrous acid NO^2+2O, &c.

(549) A method of determining ozone quantitatively has been invented by Schoenbein. This method depends upon the property possessed by ozone of decolorizing solution of indigo, a property which ordinary oxygen is altogether destitute of. To prepare his "test" solution he takes 100 milligrammes of indigo solution, adds an equal quantity of hydrochloric acid, and heats the whole till it boils. He then adds to the hot solution small portions of a dilute solution of chlorate of potash (about one per cent.), shaking the mixture continually, until it has become of a brownish yellow colour. If, for example, 100 milligrammes of chlorate have been employed to decolourize the indigo solution, he infers that this effect has been caused by the 39 milligrammes of oxygen contained in that quantity of the salt; and, consequently, that 1 milligramme of oxygen is capable of decolorizing 100·39 grammes of the solution of indigo. To render this solution of such a strength, that exactly 10 grammes of it are decolorized by 1 milligramme of oxygen, he mixes 100 parts of it with 290 parts of water, and preserves it in stoppered bottles.

In order to determine the quantity of ozone in, say, 30 litres of air, acted upon to the greatest possible extent by phosphorus, he pours 300 grammes of the test solution into a glass, and adds about one-half to the gas at once; the closed flask is then shaken up for some minutes, and a small quantity of the liquid poured out, to see if it is decolorized; if so, he dips a small strip of moist iodide of potassium paper into the vessel, and if this is coloured, adds more solution of indigo, until the decolorization is complete, when the quantity of solution employed gives the amount of ozone in the gas.

Schoenbein's recent experiments have shown, that air may be ozonized to the extent of $\frac{1}{1300}$ by means of phosphorus; and did not

ozone act so energetically upon phosphorus, a much higher degree of ozonization might be attained. At this point, however, the production and consumption of this substance appear to be equal, and ignition of the phosphorus takes place in consequence of the rapid oxidation. Air, diluted with $\frac{1}{500.000}$th of its volume of ozone, may be recognized by its smell; pure ozone must, therefore, have a most intense odour.

(550) The remarkable oxidizing power of "voltaic" oxygen was pointed out by Kolbe. (*Phil. Mag.*, vol. xxx., p. 334.) By it, he was able to decompose compounds which withstood the action of the most powerful decomposing agents, such as *nitric*, *nitro-hydrochloric*, and *chromic* acids; and in some experiments he produced perchloric acid in an *acid* solution, which cannot be done, without the battery, in any but an alkaline solution. By passing the current, from four elements of Bunsen's pile, through a mixture of sulphuric acid and chloride of potassium, first chlorate and then perchlorate of potash, was formed; a concentrated solution of chloride of ammonium evolved hydrogen at the negative pole, and *chloride of nitrogen* appeared in the form of oily drops at the positive platinum pole, which decomposed, with a more or less violent explosion, on bringing the two poles into contact.

(551) The latest experiments on ozone are those of Dr. Baumert. (*Phil. Mag.*, vol. vi., p. 51.) When perfectly dry ozone, obtained by electrolysis, is passed through a long narrow glass tube, lined with a thin coating of anhydrous phosphoric acid, nothing takes place till the tube is heated; the ozone is then decomposed, and *water is formed*, which dissolves the anhydrous phosphoric acid, proving, according to the author, that ozone obtained by electrolysis contains hydrogen as well as oxygen. The quantity of ozone obtained by electrolysis is exceedingly small; 150 litres of explosive gas, obtained from 76 grammes of acidulated water, only contained 1 milligramme of ozone; and 10 litres of gas, from solution of chromic acid, containing a little sulphuric acid, gave the same quantity.

The method of analysis adopted by Baumert, was founded upon the property of oxygen, united with the elements of water, to separate an equivalent of iodine from a solution of iodide of potassium, like free bromine or chlorine, caustic potash being formed. The amount of iodine set free was ascertained by a standard solution of sulphurous acid, the point of neutralization being determined by a solution of starch.

By a series of experiments, conducted with extraordinary care, and under the direction of that great master of gaseous analysis, professor Bunsen, "electrolytic ozone" was inferred to be a teroxide

of hydrogen—HO^3 giving up its oxygen readily to oxidizable substances, and forming water.

Baumert does not, however, undertake to say, that the body obtained by the passage of electric sparks through dried oxygen is the same compound; on the contrary, by passing a stream of sparks from an inductive coil, through electrolytic oxygen, completely freed from ozone by heat, and from watery vapour by phosphoric acid, the ozone of Becquerel and Fremy, which Baumert calls *allotropic* oxygen, was formed in abundance, and was made apparent by the decomposition of iodide of potassium.

(552) *Electro-chemical polarity of gases.*—The fact, that when two wires, forming the terminals of a powerful battery, were placed across each other, and the voltaic arc taken between them, the extremity of the wire proceeding from the positive end of the battery was rendered incandescent, while the negative wire remained comparatively cool, was first observed by Gassiot in 1838, (405) and Grove shortly after threw out the idea, that the phenomenon might possibly be explained by supposing that in *air*, as in water or other electrolyte, the oxygen or electro-negative element was determined to the positive terminal; and that, from the union of the metal with that oxygen, a greater heating effect was developed.

(553) The following beautiful experiment is described by Grove: (*Phil. Trans.*, 1852, part 1.) It was made with a well-insulated nitric acid battery of 500 cells. Two wires of platinum, $\frac{1}{40}$th of an inch in diameter, forming the terminals of the battery, were immersed in distilled water; the negative wire was then gradually withdrawn, until it reached a point $\frac{1}{4}$th of an inch distant from the surface of the water. A cone of blue flame was now perceptible, the water forming its base and the point of the wire its apex: the wire rapidly fused, and became so brilliant that the cone of flame could no longer be perceived, and the globule of fused platinum was apparently suspended in air and hanging from the wire; it appeared sustained by a repulsive action, like a cork ball on a *jet d'eau*, and threw out scintillations, in a direction away from the water. The surface of the water, at the base of the cone, was depressed, and divided into little concave cups, which were in a continual agitation. When the conditions were reversed, and the negative wire immersed, the positive wire being at the surface, similar phenomena ensued, but not nearly in so marked a manner, the cone was smaller, and its base much more narrow in proportion to its height.

This experiment, the beautiful effects of which require to be seen to be appreciated, indicates a new mode of transmission of Electricity, partaking of the *electrolytic* and *disruptive* discharges.

(554) The enormous heating powers and consequent destruction of the terminals, rendered it impossible to follow out this phenomenon with the voltaic battery, and Grove, therefore, resorted to Rhumkorff's new arrangement of the inductive coil machine by which an auroral discharge in the vacuum of an air pump, 5 or 6 inches long, and in air of ordinary density, a spark of ⅛th of an inch long can be obtained. With this apparatus the following experiments were made:—

1°. On the plate of a good air-pump was placed a silvered copper plate, such as is ordinarily used for Daguerreotypes, the polished surface being uppermost. A receiver with a rod passing through a collar of leathers was used, and to the lower extremity of this rod was affixed a steel needle which could thus be brought to any required distance from the silver surface. A vessel containing potassa fusa was placed in the receiver, and a bladder of hydrogen gas was attached to a stop-cock, another orifice enabling the operator to pass atmospheric air into the receiver in such quantities as might be required. A vacuum being made, *hydrogen gas and air* were allowed to enter the receiver in very small quantities so as to form an attenuated atmosphere of the mixed gases. Two small cells of the nitric acid battery were used to excite the coil machine and the discharge from the secondary coil was taken between the steel point and the silver plate; the distance between these was generally 0·1 of an inch. When the plate formed the *positive* terminal, a dark circular stain of oxide rapidly formed on the silver, presenting in succession yellow, orange, and blue tints, very similar to the successive tints given by iodizing in the ordinary manner a Daguerreotype plate. Upon the poles being reversed, and the plate made negative, the spot was entirely removed, and the plate became perfectly clean, leaving, however, a dark polished spot, occasioned by molecular disintegration, and therefore distinguished from the remainder of the plate. In an air vacuum, oxidation took place whether the plate was positive or negative, but more rapidly when positive. In a hydrogen and nitrogen vacuum there was no discoloration, but a plate oxidized in an air vacuum was rapidly and beautifully cleared off by discharge in a hydrogen vacuum, most rapidly when the plate was negative. By making an iodized silver plate negative in an atmosphere of hydrogen, the iodine was removed in a circle or disc opposite the point which formed the positive terminal. The phenomena were all produced, though not so distinctly, with the common electrical machine. When there is too great a proportion of oxygen or air, oxidation takes place at both poles; when too much hydrogen, reduction takes place at both.

(555) The following theory has been proposed by Mr. Grove to account for these singular phenomena. The discharges being interrupted, as is evident from the nature of the apparatus, the gaseous medium is polarized anterior to each discharge, and polarized not merely *physically*, as is generally admitted, but *chemically*; the oxygen or *anion* being determined to the positive terminal or anode, and the hydrogen or *cation* to the negative terminal or cathode. At the instant producing discharge, there would be a molecule or superficial layer of oxygen or of *electro-negative* molecules in contact with the anode, and a similar layer of nitrogen or *electro-positive* molecules in contact with the cathode; or, in other words, the electrodes in gas would be polarized as the electrodes in liquids are. The discharge now takes place, by which the superficial termini of metal or oxide, as the case may be, are highly ignited, or brought into a state of chemical exaltation at which their affinities can act; the anode thus becomes oxidated, and the cathode, if an oxide, reduced.

Assuming this view, we get a close approximation, or identity in fact, to the state of polarization in gaseous non-conducting dielectrics, and electrolytes anterior respectively to discharge or to electrolysis. The experiments seem to show that, in induction across gaseous dielectrics, there is a commencement, so to speak, of decomposition, a polar arrangement, not merely of molecules irrespective of their chemical characters, but a chemical alternation of their forces, the electro-negative element being determined or directed, though not travelling, in one direction, and the electro-positive in the opposite direction.

(556) The chemical polarity of gases associates itself with Grove's experiment, verified by Gassiot (324) (*Phil. Mag.*, Oct., 1844), in which signs of electrical tension are exhibited when discs of copper and zinc are closely approximated, but *not brought into contact*, and then separated, the intermediate dielectric being polarized, or a radiation analagous, if not identical, with that which produces the images of Möser* taking place from pole to pole. In some experiments a series of zones or circles appeared on the plate, exhibiting an alter-

* The phenomena discovered by Möser, and known as *Möser's figures*, may be observed thus: place a coin upon the surface of a piece of looking-glass, or of common glass having the back covered with tin-foil, and allow a few sparks to fall upon the coin from the prime conductor of an electrical machine. Quickly remove the coin, and gently breathe over the surface of the glass, when the outline of the impression on the coin will become beautifully defined upon the glass in drops of watery vapour. If a series of plates are superposed, and the coin placed upon the upper one, and sparks allowed to fall upon it, the upper surface of each plate will present similar phenomena when breathed upon. These figures may be rendered visible by exposure to the vapour of iodine or mercury,

nation of oxidation and reduction, a medium capable of producing both being present. The colour of the central spot was *yellow-green*, in the centre, surrounded by *blue-green*; then a clear ring of *polished silver*, then an outer ring *crimson* with a slightly orange tint on the inner side, and a deep purple colour on the outer; the exterior portion of the spot was, as far as the eye could judge, of a colour complementary to the interior of the external ring, and the central portion of the spot of a colour complementary to the exterior portion of the ring. The phenomena may perhaps be explained by regarding them as analogous to the phenomena of interference of light. Alternations of opposite polar electrical actions in the discharges passing in the same direction, are shown in the experiments, and are considered by the ingenious author to be worthy of attention.

(557) *Generation of a voltaic current by flame.* M. Hankel and M. Buff have published papers showing, by the use of highly sensitive galvanometers, a current, apparently produced by flame, which passes from the upper to the lower part of the flame. Buff attributes this current to thermo-electricity, the flame being a conductor, and two metals in contact with different parts of it, the thermo-current passes from the hotter to the cooler metal, and hence the result. Mr. Grove (*Notices of the Meetings of the Royal Institution*, Feb. 3, 1854), in studying this subject, and without having then read the papers of Hankel and Buff, found the results so varying in ordinary flame that he could come to no satisfactory conclusion; he was then led to think that as, in the flame of the blow-pipe, the direction or line of combustion is more definite than in ordinary flame, he might get more definite results. He experimented with the latter flame, and immediately got very distinct evidence of a current not due to thermo-Electricity, as it could be made to conquer both the effect of the thermo-flame-current noticed by Buff, and of any thermo-current excited in the junction of the wires exterior to the flame.

This current, which Mr. Grove termed the current proper, moves from the root towards the point of the blow-pipe flame; the best points for placing the collecting spirals or plates of platinum, being for the one, a little above the root or base of the blue cone, and for

quite as well as by breathing upon them.*—*Elem. Nat. Phil., by Golding Bird and Charles Brooke.*

* "Manifold," says Humboldt, "are the sources of terrestrial light; and we may even imagine it as existing latent, and not yet set free from combination with vapours as a means of explaining Möser's pictures produced at a distance—a discovery in which reality as yet presents itself to us like the unsubstantial images of a dream."—*Cosmos, Sabine's translation*, vol. i. p. 189.

the other, in the full yellow flame a little beyond the apex of the blue cone. As the latter metal is much more heated than the former, the thermo-current is opposed to, and though it by no means destroys, it tends to weaken the effect of the flame current proper: if then, this metal can be adventitiously cooled, we should have the two currents co-operating, instead of conflicting: and so experiment proved; for by using a capsule of platinum filled with water in the full flame, and a coil or sheet of platinum foil at the base, a very marked current resulted. By arranging in a row of jets worked by a large bellows, a sheet of platinum föil placed first over the roots of the flame, and a trough of platinum foil filled with water just beyond the points of the blue cones, the large galvanometer of the Institution was deflected to 30° or 40°, the deflection being in the reverse direction upon reversing the connections respectively with the plate and trough. The same apparatus will also readily decompose iodide of potassium, iodine being evolved at the platinum point in connection with the trough. Mr. Grove is at present disposed to regard this phenomenon as a current produced by chemical action: the platinum at the commencement of action representing the zinc, which burns or combines with oxygen; that at the conclusion, representing the platinum, or the points where chemical action concludes and a tendency to reduction or deoxidation is manifested, the distinction being that the generative chemical action, instead of taking place as in the ordinary battery, only at the zinc surface, and being simply transmitted by the electrolyte, takes place throughout the intervening section of flame; and thus, within certain limits, the intensity of the Electricity increases with the distance of the plates, instead of decreasing, as in the ordinary battery.

CHAPTER X.

ELECTRO-PHYSIOLOGY.*

Historical notice—Recent researches of Matteucci and Du Bois Reymond—Electric fishes—The torpedo—The gymnotus—The silurus—Electricity of plants.

(558) "IT may be proved," says M. Arago, "that the immortal discovery of the voltaic pile arose in the most immediate and direct manner from a slight cold with which a Bolognese lady was attacked in 1790, for which her physician prescribed the use of *frog-broth.*"

There is scarcely a work on the subject of Galvanic Electricity in which this account of its origin is not given in some form or other. The author of the article "Voltaic Electricity," in the *Encyclopædia Britannica*, writes thus: "When one of Galvani's pupils was using an electrical machine, a number of frogs were lying skinned on an adjoining table for the purpose of cookery. The machine being in action, the young man happened to touch with a scalpel the nerve of the leg of one of the frogs, when to his great surprise the leg was thrown into violent convulsions."

(559) Dr. Lardner, in the introduction to his treatise in the *Cabinet Cyclopædia*, after repeating the above account, adds, "This was the first, but not the only or chief part played by *chance* in this great discovery.

"*Galvani was not familiar with Electricity;* luckily for the progress of science, he was more an anatomist than an electrician, and beheld with sentiments of unmixed wonder the manifestation of what he believed to be a new principle in the animal economy; and, fired with the notion of bringing to light the proximate cause of vitality, engaged with ardent enthusiasm in a course of experiments on the effects of Electricity on the animal system. It is rarely that an example is found of the progress of science being favoured by the ignorance of its professors.

"*Chance* now again came upon the stage. In the course of his researches he had occasion to separate the legs, thighs, and lower parts of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected,

* This chapter, as far as par. 643, has been compiled principally from Matteucci's "Phenomenes Electro-phopiologiques des Animaux.

he passed copper hooks through part of the dorsal column which remained above the junction of the thighs, for the convenience of hanging them up till they might be required for the purpose of experiment. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence."

(560) Dr. Thomas Young, in his Lectures on Natural Philosophy, shortly alludes to the circumstance thus: "The first circumstance that attracted Galvani's attention to the subject of animal Electricity, was the agitation of a frog that had a nerve armed, that is, laid bare and covered with a metal, *when a spark was taken in its neighbourhood. A person acquainted with the well-known laws of induced Electricity might easily have foreseen this effect.* It proved, however, that a frog so prepared was a very delicate electrometer, and it led Galvani to further experiments."

(561) The author of the treatise on Galvanism, in the *Library of Useful Knowledge*, repeats the old story of the "frog-soup," and we re-echoed it in the last editions of this work. It appears, however, that we have all been guilty of considerable injustice towards Galvani; and that, so far from his being unacquainted with Electricity at the time he made his important observation, he had been for many years studying it in connection with the muscular contractions of frogs, as appears from a draft found among his manuscripts, which, with his memoirs, have been collected by M. Gherardi, and published by the Academy of Sciences of Bologna. This draft bears date 6th November, 1780, *i. e.*, eleven years before the publication of his Commentary. It is worthy of remark, that in the description of the first experiment there occurs the words, "The frog was prepared as usual," which sufficiently proves that this was not his *first* experiment with frogs.

(562) In the year 1678, the following experiment was made by Swammerdam, before the Grand Duke of Tuscany; it will be perceived that it is identical with the celebrated experiment of Galvani, though there can be no doubt that the Bolognese philosopher was entirely ignorant of it. Into a cylindrical tube of glass was placed a muscle, the nerve of which was enveloped with a small silver wire, in such a manner that it could be raised without injury. The first wire was passed through a ring, bored in the extremity of a small copper support, soldered to a sort of piston or partition; but this small silver wire was disposed in such a manner that, on passing between the glass and the piston, the nerve could be drawn by the hand so as to touch the copper, *the muscle immediately contracted.*

In the year 1767, the sensation experienced in introducing the tongue between two plates of dissimilar metals, and then bringing them into contact, was described by Sulzer in a work entitled "General Theory of Pleasure."

(563) From documents in the possession of the Institute of Bologna, it appears that Galvani was engaged with experiments on the contractions of the muscles of frogs at least twenty years before the publication of his famous Commentary. The story of the frog-soup may, therefore, henceforth be treated as a romance; and it is unfair to question Galvani's electrical knowledge, from the circumstance of his feeling surprised at observing the contraction of the prepared frog when a spark from the conductor of an electrical machine was drawn near it. Any other philosopher, as Matteucci * justly observes, would at that time have felt surprised on witnessing the phenomenon for the first time; and, in fact, in a Latin memoir on electrical light in air of different densities, Galvani sufficiently shows his acquaintance with Electricity, both theoretically and practically; and, in a memoir "on the use and activity of the conducting arc," he suggests that the contraction of the frog may be explained by the *return shock*.

In pursuing his researches, Galvani submitted the frog to the passage of atmospheric Electricity; and it was in these experiments that he discovered that the frog, properly prepared, is of all electroscopes the most delicate. We cannot read, without a shudder, Galvani's account of a daring experiment made by him April 7th, 1786, whilst engaged in these investigations. He grasped in his hands the rod of an insulated atmospheric conductor at the very moment when lightning was flashing through the skies!

(564) The first experiment with a metallic arc is described in the third part of Galvani's Commentary. The note in which it is found registered bears date Sept. 20, 1786, and contains, in Galvani's own handwriting, the words "Experiments on the Electricity of Metals."

The primary fact of the contraction of the frog suspended by a *copper* hook from an *iron* stem in the neighbourhood of an electrical machine in action was studied by Galvani with great care; in it he saw that the contraction took place when the extremities of a metallic arc, formed of two different metals, united together, touched at one point the nerves, and at the other the muscles of the frog. In two different parts of his Commentary, Galvani insists on the advantage in this experiment of employing a metallic arc, composed of two *different* metals instead of one. He also states that the con-

* Treatise on the Electro-physiological Phenomena of Animals.

tractions may be obtained by uniting with a metallic arc two capsules filled with water, in which the frog is so disposed as to have its lumbar nerves in one of the capsules and its legs in the other. Lastly, he ascertained that the metal composing the arc in this experiment should be chosen amongst the least oxidable metals, such as gold or silver, to obtain the greatest and most prolonged contractions; and he minutely describes all the circumstances which prove that the phenomenon is an electrical one.

(565) Galvani supposes the existence of an *Animal* Electricity, a *nervous fluid* condensed in the interior of the muscle. The nerve, according to him, was only the conductor of the discharge of the two electricities contained in the muscle. The apparent homogeneity of the structure of muscle does not vitiate this hypothesis, tourmaline presenting an analogous phenomenon. In one part of his Commentary, Galvani expressly says, that many of the contractions obtained with a metallic arc are due *to the arc itself*.

Other of Galvani's memoirs relate to the following subjects: the use and activity of the conducting arc in muscular contractions; the action of the arc composed of a single metal; of water and carbon; of water alone, or of the human body; of a metallic arc of unequal surface; the contractions excited in a frog when the arc is interrupted, &c. To explain the action of the electrical current on muscular contractions, Galvani supposes that a change is determined in the parts of the brain.

(566) In one of his memoirs on Animal Electricity addressed to *Spallanzani*, Galvani describes the fact of the contractions excited in a prepared frog by bending back its limbs, and bringing them in contact with the lumbar nerves. The perusal of this memoir impresses one (writes Matteucci) with a high sense of the merits of Galvani as an experimentalist. It commences by establishing that the contractions excited in these famous experiments cannot be attributed to anything like *irritation* of the nerve; that the experiment is more likely to succeed if the frog be previously moistened with solution of salt; that the frog should not be operated upon till it has lost that tetanized condition which it frequently exhibits for a time after its preparation; that the contraction sometimes takes place on separating the nerves from the muscles of the leg; that it also succeeds on establishing the circuit between the nerves and legs, and morsels of muscular substance; and, lastly, that contractions are awakened by touching the nerves of the prepared frog at two different points, with a morsel of muscular substance taken from a living animal.

Galvani next studied the discharge of the torpedo, and by means

of a prepared frog he ascertained the instant of its discharge; he made also the first observations on the influence of the brain and circulation of the blood on the discharge of the torpedo.

(567) The first philosopher who repeated the experiments of Galvani was the celebrated Volta. He admitted the existence of *animal* Electricity in the muscles, and in a letter to Professor Carmenati, bearing date April 3rd, 1792, he relates all the experiments made by him to demonstrate the sensibility of the frog to electrical discharge; he next applied himself to Galvani's experiments with the metallic arc. He first ascertained that the contractions of the frog ensued on simply touching, with the extremities of the metallic arc, two points of the nervous filaments; he next discovered that it was possible with the metallic arc to produce sometimes the sensation of light, sometimes that of taste, by applying it to the nerves of the eye or tongue; and from all his experiments he drew the conclusion, that the muscular contractions in the experiments of Galvani and himself were produced by the irritation of the nerves; that this irritation may produce sometimes *sensations*, sometimes *contractions*; and that, lastly, this irritation by the metallic arc was occasioned by an electric current developed by that arc.

(568) Volta imagined that by the contact of any two heterogeneous conductors an action is developed, by which the two bodies become charged with contrary electricities, which may discharge themselves across a third not possessing the same action as the other two.

When it was objected to this hypothesis of Volta, that a *homogeneous* metallic arc was sufficient to cause contractions in the frog, he replied that a very small difference in the extremities of the arc was sufficient to produce an electric current, and that a very feeble current may irritate the nerves of a frog sufficiently to excite contractions. Thus Volta found that when one extremity of a metallic arc was heated and the other *not*—one end polished the other *not*—sufficient heterogeneity was occasioned to excite a current. In vain Galvani, Humboldt, Valli, and Aldini opposed to Volta the fact that without any metallic arc the frog may be made to contract, by simply bending back the limb, and bringing it into contact with the lumbar nerves; Volta answered that it was only to generalize his theory of electro-motive force; that it was only necessary to say that the nerves and muscles of the frog act as the two metals of the arc in order to explain the facts submitted by the partisans of Galvani.

(569) Up to this time, the development of Electricity by the contact of heterogeneous metals was only an hypothesis of Volta's. It was in the month of August, 1796, that he obtained, by means of the condenser, the first signs of Electricity developed by the contact

of two metals, and that he made his immortal discovery of the *Pile.*

The influence of this discovery over all the sciences, and the rapidity with which it spread, caused all opposition on the part of Galvani to fall into oblivion, and fifty years elapsed ere any one, save in an historical work, ventured to make any mention of *Animal Electricity.*

Volta discovered that the electric current, in its passage through the organs of sense, excites there corresponding sensations; he also found that the continued passage of the electric current through a frog weakened its action in the direction of the current, while it was still very strong whilst traversing the animal in a contrary direction.

(570) Among the philosophers who occupied a distinguished rank in the celebrated controversy between Galvani and Volta, the illustrious Humboldt stands pre-eminent. His work, entitled "Experiments on Galvanism," published in Paris in 1799, and afterwards in Germany, contains a host of excellent and important experiments. No one before him had applied the arc of Galvani to so great a number of different animals in various parts of their bodies. The action of the electric current on the movement proper of the intestines, and on the pulsations of the heart, was discovered by Humboldt. He had the courage to remove the skin from parts of his own body by means of blisters, and to subject the denuded parts to the action of the metallic arc. His experiments on the secretions from the wounds formed by the blisters are exceedingly curious. He proved on himself, that the action of the electric current was not limited to the sole instants of the commencement and the end of its passage. He studied with great care Galvani's *discovery* of the contractions obtained by bringing the legs of a frog into contact with its lumbar nerves; and he ascertained that contractions may be obtained in the prepared frog, by touching the nerve at different points with morsels of muscular substance taken from a living frog. The following is a summary of his results: strong muscular contractions were obtained, 1°, when the leg of an animal was bent back against the *ischiatic* nerves, both being organically connected. 2°. When the crural nerve and its muscle were connected by a fragment cut from the same nerve. 3°. When a connection was established between two parts of the same nerve by means of some animal tissue.

(571) Some important observations were made by Valli of Pisa in 1792; this experimentalist was the first to show that when an arc of two metals, *pewter* and *silver*, is employed, the most violent contractions are obtained when the pewter is applied to the nerves, and the silver to the muscles; he ascertained that of all metals *zinc,* when

applied to the nerves, has the most remarkable power of exciting contractions, and he noticed that when a frog had lost its sensibility to the passage of a current, it regained it by repose.

Aldini showed that contractions may be excited in a prepared frog by holding it in the hand, and plunging its nerves into the interior of a wound in the muscle of a living animal.

(572) Some interesting observations on the sensations excited in animals by the passage of the electric current through them; on the influence of cold and heat; on the muscular irritability excited by Electricity; on the reproduction of nervous substance; on the action of certain poisons; on the phenomena of muscular contraction, &c., were made by Fowler, and are alluded to in the *Bibliotheca Britannica*, May, 1796.

(573) The following is a summary of some of the contributions made by Lehot to the science of animal Electricity: He ascertained that in a recently killed animal, contractions are excited by the electric current in whatever direction it may be applied; but, when the vitality of the animal has become diminished, if the current be sent in the direction of the ramifications of the nerve, contractions are excited only at the *commencement* of the current: the contrary takes place when the current is directed contrary to the ramifications of the nerves, *i. e.*, in this case the contractions only take place when the current ceases. By studying the sensation excited by the current on the organs of taste, Lehot arrived at a most important result: the current which traverses a nerve in the direction of its ramifications excites a sensation when it ceases to pass, though this influence is only exerted at the *commencement* of its passage when the nerve is traversed in a direction contrary to its ramifications: the later experiments of Bellingeri and Marianini entirely confirm those of Lehot.

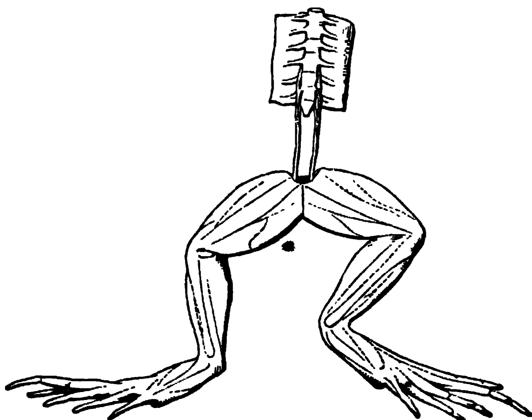
(574) After a long interval, during which the name of animal Electricity was scarcely mentioned in science, the study of it was resumed by Nobili, who published a memoir on the subject in the *Bibliotheca Universelle*, 3rd Nov. 1827. It is to this philosopher that we are indebted for the great improvements in the galvanometer. He prepared a frog *à la Galvani*, and plunging its two extremities (lumbar nerves and legs) into two capsules of salt water, he united the two vessels by filaments of moistened cotton; the frog, as in Galvani's experiment, immediately contracted: he then removed the cotton, and shut the circuit by plunging into the capsules the platina extremities of his galvanometer; a deviation amounting to 10°, 20°, and even to 30° was obtained, indicating an electrical current from the *feet to the head* of the animal. Nobili called this

current the *current proper* of the frog, and he found that it remained for several hours after the preparation of the animal, and that it could be increased by disposing the animals in a pile. Nobili endeavoured to explain this current on thermo-electric principles: to an unequal temperature in the nerve and muscle occasioned by *evaporation.*

Nobili appears to have studied more closely than any of his predecessors, the contractions excited in a frog by the passage of a current through its nerves in different directions, and according to the degree of vitality remaining in the animal. His ideas of *tetanus* and of *paralysis* are well deserving the attention of medical men.

(575) The frog is prepared for galvanoscopic experiments in the following manner:—

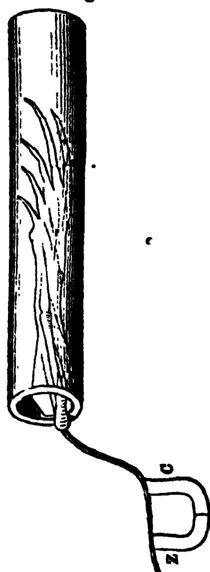
Fig. 217.



A lively animal is selected: two-thirds of the body just below the front paws are cut off, and the hind legs and pelvis, with a piece of the spinal cord, are preserved and skinned: then, by introducing the scissors between the lumbar nerves and the pelvis, and cutting the latter in two places, we obtain the frog prepared *after Galvani's plan;* it is shown in Fig. 217.

(576) In order to employ the frog in the study of the electric current, the latter must be passed along the nervous filament alone of the frog. For this purpose the frog, prepared after Galvani's plan, is cut in half, and by a very easy preparation, we are enabled to remove from the half frog, the bone and muscles of the thigh, preserving its nerve untouched. In this manner we end by having a frog's leg, to which is attached a long nervous filament, composed of the lumbar portion of the pelvis, and the crural portion of the thigh. We have only to introduce this leg into a tube of varnished glass, to have an instrument very sensible to the passage of the electric current. It is shown in Fig. 218. To employ this kind of galvanoscope, the glass tube is taken by the end opposite to that into which the leg of the frog has been introduced, and the nervous filament

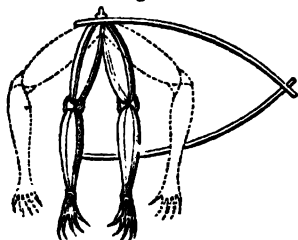
Fig. 218.



which is hanging outside the tube, is made to touch the two points of the electromotive element that we desire to study. When the nervous filament is traversed by an electric current, the leg is seen instantly to contract. Two slips of moistened paper may be placed on the two points of the electromotive element to avoid any irritation of the nerve by direct contact.

(577) To exhibit the experiment with the frog's legs generally, the legs of the frog are to be left attached to the spine by the crural nerves alone, and then a copper and a zinc wire, being either twisted or soldered together at one end, the nerves are to be touched with one wire, whilst the other is to be applied to the muscles of the leg. Fig. 219 shows the arrangement. There are several ways of varying this experiment; the following one may be practically applied to a useful purpose: If a piece of copper, as a penny, be laid on a sheet of zinc, and if a common garden snail be put to crawl on the latter, it will be observed to shrink in its horns and contract its body whenever it comes into contact with the penny: indeed, after one or two contacts it will be observed to avoid the copper in its journey over the zinc.

Fig. 219.



The Muscular Electric Current.

(578) Proof of the existence of an electric current circulating through the muscle of a living animal is obtained by introducing into a wound formed in the muscle of a living animal the nerve of a prepared frog, in such a manner that the extremity of the nerve shall touch the bottom of the wound, and another part, the edge; the frog instantly contracts. The muscular electric current may be detected in animals for some time after death, but when it has once ceased, it cannot again be renewed. It is found in *warm* as well as in cold-blooded animals.

(579) By forming a *muscular pile*, Matteucci succeeded in giving considerâble deflection to the needle of his galvanometer.

The pile was thus formed. Five or six frogs were prepared and

cut in half after Galvani's plan, great care being taken not to injure the muscle. The thighs were then cut in half, and so disposed that each half thigh should touch the following, the faces of each turning the same way, and the interior of one coming into contact with the exterior of the next; so that one of the extremities of the pile was formed of the interior of the muscle, while the other extremity was formed of the surface. The prepared plates of the galvanometer were immersed in the cavities of the board on which the pile was disposed, which cavities contained a liquid similar to that in which the plates had been prepared, the deviation amounted to 15°, 20°, 30°, 40°, 60°, according to the number of half thighs; and if the frogs were sufficiently active, a deviation of 2° or 4° was obtained with two elements, of 6° or 8° with four elements, of 10° or 12° with six elements, and so on: the liquid in the cavities being distilled water; but when a liquid of a better conductibility was employed, the deviations were considerably greater, though always in the same direction, viz., from the interior of the muscle to the surface. On leaving the circuit closed, the needle gradually returned to zero.

(580) Similar experiments were made with eels, cut into pieces, and so disposed that the muscular surface of one of the elements should touch the internal face of the next. With a pile of five elements, a deviation of 28° was obtained, with two elements a deviation of 10°, always in the same direction, viz., from the interior of the muscle to the surface. With a pile formed of muscular slices cut from the backs of tenches, analogous results were obtained; and by experimenting on warm-blooded animals, such as pigeons, chickens, oxen, sheep, &c., ample evidence was obtained to prove that whenever the interior of the muscle of a recently-killed animal is by the aid of a conducting substance brought into contact with the surface, an electrical current is established, directed from the interior to the surface, the intensity of which varies with the animal, and is increased in proportion to the number of elements disposed in the pile.

(581) In all these experiments, Matteucci was scrupulously careful in the management of his galvanometer: and the regular increase of the deviations with the number of elements, their uniform direction, whatever the liquid employed in the cavities, and the instantaneous reversal of the current by reversing the disposition of the elements, are facts which fully prove the correctness of the conclusion at which Matteucci arrived, namely, that the current, whatever its source, had its origin in the muscular masses, and was not due to adventitious circumstances introduced in the manipulation.

By closing the circuit with the nerve of the galvanoscopic frog instead of the galvanometer, a more delicate and perhaps a less

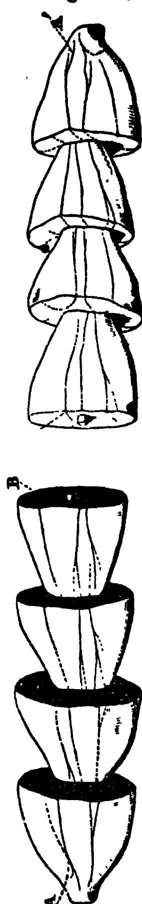
questionable method of detecting the muscular electric current was obtained. The return of the needle of the galvanometer to zero, on leaving the circuit closed, is easily accounted for, not only from the gradual diminution of vitality in the muscle, but also from the *secondary current* developed in the terminal plates, which circulates in a contrary direction to that of the pile.

Matteucci next instituted a series of experiments on living animals, the general results of which were the same as those on animals recently killed, the current in all cases moving from the interior of the muscle to its surface, or more generally from the interior of the muscle to any conducting substance in communication with that surface.

The Laws of the Muscular Electric Current.

(582) The first thing that arrests the attention in studying the muscular current in the muscles of different animals, is the difference in its duration in different cases. If an equal number of muscular elements be prepared from different animals, frogs, pigeons, rabbits, &c., and examined one after the other with as little delay as possible, commencing sometimes with one, sometimes with another, it will be found that the deviations afforded by each, though in point of number of elements they are equal, are remarkably different: thus, in one experiment made by Matteucci, with three piles each of eight elements, the pile formed of muscle of rabbit gave a deviation of 8°; that of pigeons, a deviation of 14°; that of frogs, a deviation of 22°; the current diminishing with the elevation of the rank of the animal in the scale of creation. Fifteen minutes after the first experiment, a deviation of 4° was obtained from the first pile; of 10° from the second; and of 16° from the third. One hour after the signs of the electrical current in the *rabbit* pile had entirely disappeared, from the *pigeon* pile a deviation of 2° or 3° could be obtained; while from the *frog* pile there was still a deviation of 8° or 10°; and, even after twenty-four hours, from the latter, a deviation of 2° or 3° could be made apparent.

(583) In studying the laws of the muscular electric current, M. Matteucci availed himself of the *differential current* which is produced by causing two currents to pass through the galvanometer in inverse directions, the deviations of the needles being of course in the direction of the strongest current. In applying this principle to the study of the varying circumstances of the muscular current, the two piles to be compared, both consisting of the same number of elements, A B, A′ B′, Fig. 220, are opposed to each other, as shown in the figure, their extremities being plunged into two cavities of the


Fig. 220.

wood, and the circuit shut with the galvanometer, by dipping the terminal plates in the liquid of the extreme cavities; if any difference exist in the two piles, it will be immediately disclosed by the differential current in the direction of the strongest. In this manner, Matteucci studied the influence on the intensity of the current exerted by the mass of muscle: he compared two piles opposed one to the other: one of these piles had each of its elements formed of one half thigh of a frog, whilst those of the other were formed each of two or three half thighs placed one on the other. He never obtained any very distinct signs of a differential current: the same was the case when two piles composed of muscle of rabbit were compared, one of these piles having its elements made up of large muscular slices, and the other of small slices from the same muscle. The small differential current that was obtained was in favour of the pile, the elements of which consisted of the larger quantity of muscle. Two similar piles, formed one of half thighs of frogs that had been subjected to a very low temperature, the other of an equal number of half thighs, cut from frogs in their natural state, gave a differential current of 35° to 40° in favour of the latter. The pile of cooled frogs gave from 15° to 16°, the other 45°; with warm-blooded animals the influence of temperature was less marked.

(584) When the frogs were submitted to sudden changes of temperature, being quickly cooled and then suddenly introduced into water tolerably warm, it was noticed that they not only recovered their motion, but became even more vivacious than before, and when formed into a pile they gave a stronger current than a pile composed of an equal number of frogs that had not been submitted to alternations of temperature. During the intense heat of summer the muscular current was much more feeble, and Matteucci noticed that the frogs were much less robust than at other seasons of the year, and their muscles less red and consistent.

It does not appear that the integrity of the nervous system has any influence either on the direction or intensity of the muscular currents, for when all the great nervous filaments were carefully removed from ten prepared frogs, no differential current, or only a

very feeble one, was obtained, by opposing a pile of such frogs to another of an equal number of elements from frogs in their normal state. The same was the case with pigeons, and other animals.

Again, on comparing together two piles, each of six elements, the frogs composing one having had their lower extremities paralyzed by a red-hot iron, a differential current in favour of the latter was obtained, and by submitting frogs to the action of opium, nux vomica, carbonic acid, and other narcotics, so as to stupefy them, and in that state arranging them in a pile, and comparing them with an equal number of frogs in their natural state, Matteucci was unable to detect any variation either in the intensity or direction of the current. The same results were verified with pigeons.

The influence of *sulphuretted hydrogen* on the intensity of the muscular current was, on the contrary, very remarkable, a differential current of 26° being obtained in favour of frogs in their natural condition; a pile of twelve elements of common frogs giving 30°, that of the poisoned frogs only 5° or 6°, both, however, in the same direction. The same was the case with pigeons, a differential current of 17° being obtained in favour of the bird that had not been poisoned.

Matteucci thus sums up the principal results of his experiments on the muscular current:—

1°. The intensity of the current varies for cold-blooded animals in proportion to the temperature of the medium in which they have lived for a certain time.

2°. Its duration after death is so much the *less* as the animal is more elevated in the scale of creation.

3°. The intensity varies with the degree of nutrition of the muscle, and it is always strongest in those muscles which are gorged with blood and inflamed.

4°. It is altogether independent of the integrity and activity of the motor and sensorial nervous system.

5°. The influence of narcotic poisons is null, or very feeble, on this current.

Amongst the different gaseous poisons, *sulphuretted hydrogen* acts in a remarkable manner in weakening the intensity of the muscular current, the direction of which is in every case the same.

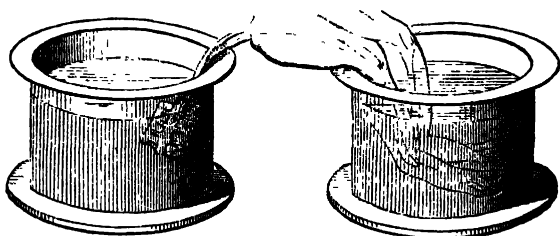
(585) More recently* M. Matteucci has added some further interesting and important information on the subject of the muscular current. He has otained signs of tension at the two extremities of his muscular piles by the aid of the condenser. He has also obtained electro-chemical decomposition by the current; and by a great number of experiments he has established that the intensity of the

* Comptes Rendus, April 14, 1845; Phil. Mag., June, 1845; Elect. Mag. vol. ii.

current is in proportion to the activity of respiration, and that is proportionate to the rank of the animal in the scale of creation, whilst its duration after death varies in an opposite ratio. He has further studied the influence of different gases, and has ascertained that the muscular pile acts equally in atmospheric air, in oxygen, in very rarefied air, in carbonic acid, and in hydrogen. In the latter gas the deviation of the needle of the galvanometer remains constant for several hours, a singularity not referrible to an action of the gas on the muscles, but to the phenomena of secondary polarity. The nullity of the action of the different gases named upon the intensity and duration of the muscular current proves that the origin of the current is in *muscle itself*, whether living or taken from the animal a short time after death; and that it is in the organization of the muscle, and in the chemical actions going on within its very structure, that the current exists, is further proved from the fact that from piles formed of fibrine, separated from the blood of a recently-killed ox, no signs of a current can be obtained.

(586) If a prepared frog be placed as shown in Fig. 221, with its

Fig. 221.



lumbar nerves plunged into one capsule filled with water, and with its legs in another, and the circuit completed with the galvanometer, the instrument gives evidence of an electrical current passing from the feet towards the head of the animal. The signs of this current, which were minutely studied by Matteucci, are much increased by arranging several frogs on an insulated surface, so that the nerve of each frog shall touch the legs of the following, as shown in Fig. 222. Every time the circuit is completed, the needle of the galvanometer moves, and the limbs of the frogs contract.

(587) It had been observed by Nobili, that on disposing the frogs in such a manner that the nerves of one should touch the nerves of the other, and the same with the muscles, no contractions took place in either: this he explained by supposing that in this case the electromotive elements were opposed. Matteucci, however, in re-

Fig. 222.

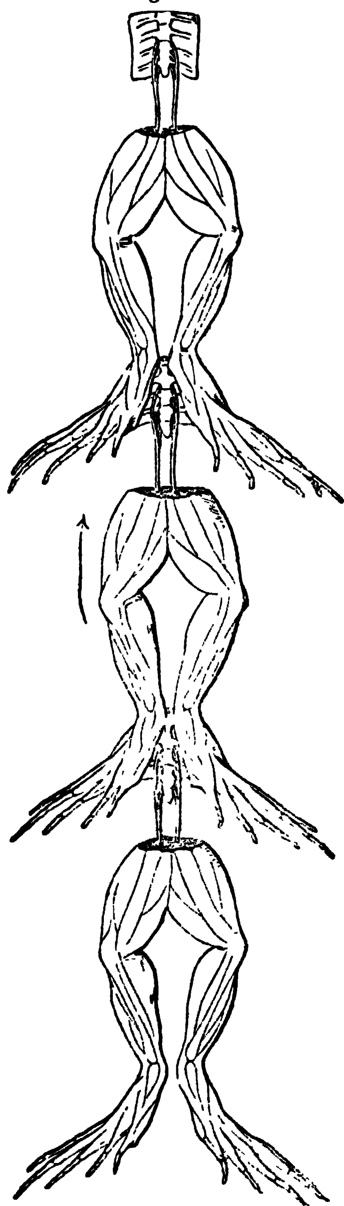
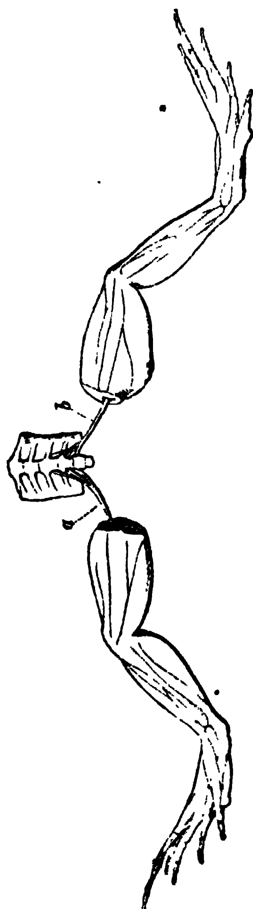


Fig. 223.



peating and varying the experiments, found that the contractions always took place, provided the parts of the two frogs touched simultaneously were not of the same kind. He experimented in the following manner: The frog, prepared as usual, was separated into two halves, but joined by the two spinal nerves organically united by a smaller piece of spinal cord, as shown in Fig. 223. On disposing the frog on an insulated plane, keeping the two thighs and the nerves attached to them well separated, and thus touching with one leg the other thigh,

contraction instantly took place, though they failed on touching the legs one with the other. Still stronger contractions took place by bending back upon one leg the nerves of the other, so that the spinal cord came into contact with the muscles of the thigh. In this manner, with a very lively frog, contractions were obtained on touching one leg with the other. Frequently the contraction is observed in one of the limbs when the circuit is shut, and in the other when the circuit is opened.

(588) By employing a galvanometer, and touching with one plate the leg and with the other the thigh, indications of a current directed from the leg to the thigh and from that by the nerve to the other thigh were obtained. If the frog was particularly lively, and experimented with as soon as prepared, it happened that on touching the muscles of one thigh with those of the other leg, contractions were awakened in the two limbs, as well on opening as on shutting the circuit; but when the animal was not very lively, or was not experimented with for some minutes after preparation, the limb alone, the muscles of the thigh of which were touched, contracted on shutting the circuit, whilst the other limb remained tranquil. On opening the circuit, the contrary was the case. From these experiments, each of the limbs of the frog are considered by Matteucci as a *complete electro-motive element*, and hence it might be anticipated that the contractions would fail on touching symmetrical parts, since the two currents of the two limbs would circulate with an equal intensity, but in contrary directions. The two limbs of a prepared frog being so disposed that the nerve of one limb and the paw of the other should dip in the liquid of a small glass, and the other paw and nerve in the liquid of another glass, no signs of a current could ever be obtained by closing the circuit by a galvanometer, evidently because those portions of the currents developed in the two limbs which passed through the instrument moved in contrary directions; but if, on the other hand, the disposition of the limbs was such that in the one vessel there were plunged the two nerves and in the other the two legs, signs of a current *were* obtained, because in this case those portions of the current which did not circulate through the animal itself took a similar direction through the galvanometer. No increased effect was obtained by increasing the number of frogs, the current from ten or twelve, heaped one on the other, being no greater than with a single frog; nor were any signs of a differential current obtained by opposing a pile of half frogs to one of entire frogs.

(589) From a laborious series of experiments, M. Matteucci drew the conclusions:—

1°. That the complete electro-motive element of the current of the frog is formed by one of its limbs, that is to say, of a leg, a thigh, its spinal nerve, and a piece of the spine.

2°. That through each of the limbs of the frog there circulates the current of the other limb, whenever the two legs are made to touch.

3°. That in experiments with the galvanometer we only get, through the wire of the instrument, the current which results from the sum of those two portions of the current of the two limbs which do not discharge from limb to limb.

Then as to the parts of the frog which are necessary for the production of what Matteucci called the *current proper*, and to the circumstances, anatomical and physiological, according to which its intensity varies, his experiments lead him to the following conclusions:—

1°. That the *current proper* of the frog persists in its intensity and direction *without* the spinal cord, or the spinal and crural nerves, and even when the animal is deprived of all the visible nervous filaments of the muscular mass of the thigh.

2°. That the electro-motive element of this current is confined to the muscles of the leg and of the thigh organically united.

3°. When there is left in the prepared frog the spinal cord, its nerves, and their ramifications through the muscles, these nervous parts act in the production of the current in the same manner as the muscular substance of the thigh.

(590) The influence of different gases on the *current proper* of the frog was next examined. Carbonic acid at first exerted no influence, but after a time it seemed to diminish the sensibility of the nerve, causing the contractions proper to cease; by exposing the animals to pure oxygen gas before preparing them no effect was produced; but Matteucci found that boiling water had the effect of extinguishing the current altogether.

(591) With a pile composed of legs alone, a current was produced equal to that from the same number of entire frogs; the direction of the current being from the extremity towards the head, but with a pile composed of thighs alone, sometimes with the nervous filament attached, sometimes with it removed, a very feeble current only was obtained. When the tendinous surface of the limb was removed as much as possible, a current was obtained sensibly *more intense* than when the tendon was untouched, proving that the *current proper* may be obtained from the leg alone. Matteucci did not find, with Galvani and Humboldt, that the *contractions proper* became feebler by removing the tendons from the muscles of the leg: on the contrary, he could find no other difference in the two cases, than that the con-

tractions were extinguished quicker when the tendons were removed. When the blood was drained from the bodies of the animals;—when they were poisoned by sulphuretted hydrogen, or stupefied by nux vomica, very feeble signs of the current or contraction could be obtained. When slight wounds were inflicted on the muscles of the thighs of frogs, so that they became red and inflamed, but did not lose blood, both the *current proper* and the *contraction proper* were increased; on the other hand, the effect of *cold* was always to diminish, and frequently to destroy, both, though both were always regained by restoring the animal to its proper temperature.

(592) From a pile of four frogs' legs, to which were left attached a long nervous filament, composed of all the lumbar part and of the crural part concealed in the thigh, the nervous filament resting on the extremity of the leg of each element, (Fig. 224,) a deflection of

Fig. 224.



4° or 5° in the direction of the *current proper* (from the feet towards the head of the animal) was obtained: but when in the same pile the nervous filament of each leg was bent back, and contact made between the inferior and superior extremities of the limb, a deflection of 10° or 12° was obtained. The presence of the nerve has, therefore, no other effect than that of weakening the current, which is very natural, if we reflect on the bad conductibility of the nervous substance, on the greater length of the circuit, its small diameter, &c.

(593) Matteucci prepared eight frogs' thighs by removing the legs and leaving the lumbar nerves; he then cut the thighs nearly in half, taking care to preserve the nervous filaments, and formed them into a pile, by connecting the nervous filament of one thigh with the muscular surface of the next half thigh. This pile gave him 12° muscular current, which in this case was directed from the interior of the muscle to the *nerve* in the animal, or rather from the nerve to the surface of the muscle. In this experiment, the nervous filament acted as the interior of the muscle in which it ramified.

(594) The same experiment may be made with the legs of pigeons and rabbits; for this purpose the nervous filament of the limbs or the crural nerve which lies beneath the muscle must be exposed, and the pile formed by bringing the nerve of each element into contact

with the surface of the muscle, the current developed is always feebler than when the nervous filament does not form a part of the circuit.

The nerve may, therefore, be considered as acting merely the part of a bad conductor, representing the electrical state of that part of the muscle nearest to it.

(595) The following experiments were made in confirmation of this: Let a number of frogs' thighs be prepared by divesting them of their legs and lumbar nerves; let them be cut in half, removing the *inferior* half thigh, instead of the *superior* as in the preceding experiment; and then let them be formed into a pile, making contact between the nerve and the interior of the muscle, a *muscular current* directed from the interior of the muscle to the surface (the nerve in this case) will be obtained. Here, then, we find the same direction in the muscular current relatively to the same parts, interior and surface of the muscle; as to the nerve, however, the direction of the current is reversed.

Again, let a number of half frogs be prepared, the upper half of each of the thighs being removed, so that each element is composed of a leg united to a half thigh. Let them be formed into a pile, contact being made between the under part of the leg and the interior part of the muscle of the half thigh, a current will be obtained in the direction of the current proper, but much feebler than that given by a pile composed of an equal number of entire half thighs.

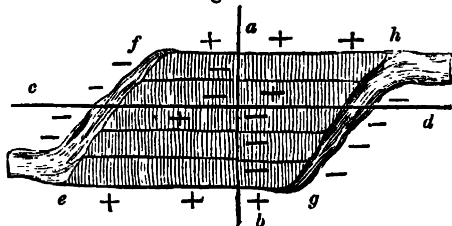
(596) This result was considered as a necessary consequence of the existence in the animal of a *current proper* and a *muscular current*. It must be remembered, that the leg alone of the frog gives the *current proper*, and that the muscular current given by the half thigh is directed always from the interior of the muscle to the surface. It follows, then, that in this pile there must be *two* currents circulating in contrary directions, which necessarily mutually weaken each other, and since in this disposition a current in the direction of the *current proper* is obtained, it follows, that in the limbs of the frog this current is more intense than the muscular current. The function of the nerve was that of a feebly conducting body which represents the electrical state of that part of the muscle which is nearest to it.

(597) From these and numerous other experiments, M. Matteucci came to the conclusion that there are two distinct currents, viz.: 1°. The *frog current*, an upward Electro-motive power in the leg of the frog and peculiar to this animal alone; and 2°. *A new current* common to the frog and all warm-blooded animals according to which the *surface* of the muscle, including the expansion of the tendon, is *positive* in relation to the *interior* of the muscle, the nerve which ramifies in the

muscle, and the whole nervous system. In the latter part of the year 1842, the subject was taken up by Dr. Du Bois Reymond, who in January, 1843, published a paper (*ann : der Physick und Chemie Bd.* lviii. s. 1.) in which he showed: 1°. That currents in all respects similar to the so-called frog current, may be observed in any limb of any animal, whether cold or warm-blooded. These currents in some limbs are directed upwards, as in the frogs' legs—in others, downwards. They are of different intensities in different limbs. But their intensity and direction are always the same in the same limb of different individuals. of the same species. 2°. That the Electro-motive action on which these currents depend does not arise from the contact of heterogeneous tissues, as Volta supposed, for the different tissues, the nerves, muscles, and tendons, in an electric point of view, are quite homogeneous. 3°. That these currents are produced by the muscles. If any undissected muscle of any animal be brought into the circuit longitudinally, it generally exhibits an Electro-motive action, the direction of which depends on the position of the muscle on the ends of the galvanometer circuit.

(598) By *longitudinal section* of the muscle, Du Bois Reymond understands a surface formed only by the *sides* of the fibres of the muscles considered as prisms. By *transverse section* of the muscle, he understands a surface formed by the *base* of the fibres of the muscles again considered as prisms. Both the transverse and the longitudinal section may be either *artificial* or *natural* ones. Thus, in Fig. 225 a section through *a*, *b*, would be an artificial transverse one; and a section through *c*, *d*, an artificial longitudinal one.

Fig. 225.

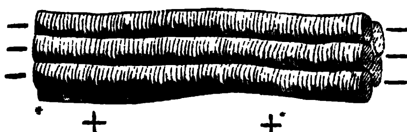


A natural transverse section is at each end of the muscle formed by the ends of all the fibres, and hidden beneath a coating of tendinous tissue, which is in connection with the tendon itself and in an electric point of view plays the part of an indifferent conducting body (*e*, *f*, *g*, *h*, in the diagram). The natural longitudinal section of the muscle is that part of its external surface which extends from one natural transverse section to the other, being free from the tendinous coating and exhibiting the red colour peculiar to muscles (*f*, *h*, *e.g.* in the diagram).

(599) The law of the muscular current may therefore be shortly expressed as follows: "*Any point of the natural or artificial longitudinal section of the muscle is positive in relation to any point of the*

natural or artificial transverse section." By means of this law, it is very easy to understand why the muscular current in one instance appears to be an upward, in another a downward one, according as the under or the upper of the two transverse sections is made to touch one of the ends of the galvanometer wire, whilst the other end is applied to the longitudinal section of the muscle. Again, according to this law, every particle of a muscle, however minute, ought to produce a current in the same manner as the whole muscle or as a larger piece of it. This consequence is true even as regards shreds of muscle consisting of only a few primary fibres. Fig. 226 represents the simplest case of the muscular current observed by Dr. Du Bois Reymond, the primary fibres being magnified 75 times.

Fig. 226.



The nerves, according to Du Bois Reymond's observations, are possessed of an Electro-motive power, which acts according to the same law as the muscles. Whilst still in organic connection with the muscles, and forming part of a circuit in which the muscles give rise to a current, the nerves simply play the part of an inactive conducting body, provided their own current be prevented from entering the circuit.

Physiological Phenomena produced by a Muscle during Contraction.

(600) The nervous filament attached to the leg of a prepared frog being made to touch the thighs of another frog, both insulated, and the lumbar nerves of the latter being touched with a voltaic pair, contraction takes place not only in the muscles of the frog touched, but also in the leg of the other; the same happens if the lumbar nerves be irritated with a pointed instrument, contraction always taking place in the second frog, provided the contraction in the muscles of the first be sufficiently strong. The same experiment may be successfully repeated with a rabbit; but Matteucci found that when the nerve of a prepared frog's leg was laid on the bared muscle of the thigh of a living rabbit, and the latter made to contract by a pile, contraction was at the same time produced in the leg of the frog. If a thin plate of gold, or any very thin insulating substance be interposed between the muscle and the nerve, no contractions are excited in the second frog; but they are not prevented by a layer of thin unsized paper. The phenomena cannot, therefore, be attributed to any mechanical action exercised on the leg by its nerves.

(601) M. Becquerel, with whom M. Matteucci repeated these

experiments, after satisfying himself that an insulated plate, even when extremely thin, prevented the action of the muscles from causing contraction in the nerve of another animal laid upon them, came to the conclusion that the phenomenon is only to be explained by admitting an electrical discharge during the act of contraction. At the instant the frog contracts, he supposes that there is an electrical discharge through the extremity of the nerve of the leg, when this extremity is placed on the muscle, or when it is separated from it by a band of moistened paper only: it discharges through gold leaf because this conducts Electricity better than the nerve, a fact analogous to that observed on placing a torpedo in a metal vice which is held in the hand. In this case, the discharge takes place through the metal, not through the hand. All these effects can be produced only from derived currents, and we must, therefore, admit the production of an electrical discharge at the instant of the contraction of the muscle. "If," says M. Becquerel, "experiments undertaken in another direction should confirm the consequences to be deduced from the experiments of Matteucci, this philosopher will have discovered one of the most important properties of the muscles while under the empire of life, or even for some time after death."

(602) M. Matteucci spared no pains in endeavouring to obtain a satisfactory solution of this problem; but his experiments were not attended with results that were altogether conclusive. He commenced by shutting the circuit of a muscular pile, composed of living animals, with the galvanometer, taking care that the needle was arrested at a certain deviation, and he then aroused contractions in the muscles in such a manner as to avoid augmenting directly the pre-existing current. To avoid all chances of error, it was necessary to avoid augmenting the conductibility of the pile; indeed, if this care be not taken, it might be supposed that, although the contractions be followed by an augmentation of the intensity of the current, this second effect may be due to the better conductibility of the pile, which allows the muscular current to circulate more easily. In experimenting with muscular piles, it is found that, though the first deviation may be considerable, the needle finally rests at a comparatively very small angle. Matteucci tried in vain to compose piles of a certain number of elements, with living pigeons fixed on a board. He then resorted to frogs, operating with the current proper. He prepared a pile of eight or ten elements, and shut the circuit with the galvanometer. The deviation, which at first amounted to 40° or 50°, settled at 6° or 8°; when the needle was nearly stationary the frogs were to be caused to contract. Here was the difficulty. His first idea was to pass an electrical current through them; but as one part

of this current would pass through the galvanometer, it soon became evident that this plan would not answer. Irritation of the spinal marrow was then resorted to; but although in some cases an augmentation of the deviation, amounting to from 3° to 4°, was observed, nevertheless it proved so difficult to preserve the integrity of the circuit, owing to the violence of the contractions, that nothing like a definite result could be obtained. Chemical agents were then employed; an alkaline solution applied to the lumbar nerves gave the best results. The contractions were not so violent, and they remained longer, and they were followed by an advance of the needle of the galvanometer of 5°, 6°, and sometimes of 10°. That this was not due to an increased conductibility of the surfaces in contact between each frog, was proved by the effect failing on the second application, and the circumstance of acids and salts not augmenting the deviation; neither was it occasioned by a chemical action, exercised unequally on the nerves and muscles, giving rise to a current moving in the same direction as the current proper. This, Matteucci proved by a series of well-contrived experiments. In summing up his results, however, he says: "I cannot say that the question is completely solved, and I must stop, not knowing how to proceed in the investigation."

(603) More recently this curious subject has been investigated by M. Du Bois Reymond, and an explanation, founded on the following law, offered: "When any point of the *longitudinal* section of a muscle is connected by a conductor with any point of the *transverse* section, an electric current is established which is directed in the muscle *from* the transverse to the longitudinal section; in other words, the real seats of the electro-motive action are not only the separate muscles which compose the limbs, but the separate fibres which compose these muscles." If the transverse and longitudinal section of a muscle be in any way connected by the nerve of the prepared limb, a current will proceed through the said nerve from the latter section to the former. This current announces itself by the contraction of the muscle of the prepared limb on first making contact. The contractions cease when the current is fairly established in the nerve; and on breaking the circuit, they are again observed. But it is not on the closing or the breaking of the circuit alone that the contractions are produced; every sudden fluctuation of the current traversing the nerve is accompanied by contractions. Applying this to the case before us, we find that the current of the muscle against which the nerve of the prepared limb rests, circulates through the said nerve. When the muscle is tetanized, this current is diminished at each convulsive effort, and its fluctuations are

answered by corresponding contractions of the prepared limb. In reply to this, Matteucci denies that the nerve touches two portions of the muscle in the manner described by Du Bois Reymond, but the Paris Academicians seem to have been satisfied with the explanation, for they came to the decision "that the above fundamental fact furnishes a direct explanation of the *induced contraction* of Matteucci."

The Influence of the Electric Current on living or on recently-killed Animals.

The general laws of the contractions and sensations excited by the electric current in nerves motor and sensitive.

(604) On applying the poles of a certain number of elements to any part whatever of the body of an animal living or recently killed, we find that they are seized with convulsions, which are sometimes so violent and so general that one almost fancies that the dead animal is restored to life (446). We read in the annals of the science, of experiments made at the period of the discovery of the pile, which induced some savants to imagine that they had discovered the principle of life, merely from observing the grimaces produced by the electric current in the facial muscles of decapitated animals.

Happily for science, this infatuation did not last long, and men betook themselves, to a serious study of electro-physiological phenomena. To commence with a general exposition of these phenomena: When a pile of from fifteen to twenty couplets is made to act on the living animal, taking care to include a portion of the nervous system, it contracts, crooks its back, and utters a cry. If the current be very strong, these phenomena persist when the circuit is kept closed; but usually it is only when the circuit is formed and interrupted that they occur. By operating on animals recently killed, the same phenomena, with the exception of the signs of suffering, take place, and of all animals the prepared frog is the most sensible to feeble electrical currents.

(605) According to Nobili, the vitality of the nerve of a recently-killed animal may be divided into *five periods*, in each of which the action of the electric current differs. In the *first period*, the *direct* current—*i. e.* that directed from the brain to the extremities of the nerves—produces contractions in the inferior muscles when it *commences* and when it *ceases* its passage: the same phenomena are produced by the *inverse* current. In the *second period*, when the nerve begins to be less sensitive, the *direct* current produces contractions at its commencement, while they become very feeble at the instant it ceases to pass. The *inverse* current does not produce con-

tractions on entering, but always on ceasing. In the *third period*, contractions are only produced at the *commencement* of the *direct*, and at the interruption of the *inverse* current. In the *fourth period*, there is only contraction when the direct current commences; and in the *fifth* and *last period*, the action of the current on the nerves is in every case null.

(606) According to Marianini, the electric current transmitted through a nervous trunk well insulated, produces contractions in the inferior muscles in two cases only, viz., when the *direct* current commences, and when the *inverse* current is interrupted. The same philosopher, by repeating with extreme care the experiments of Lehot and Bellingeri, came to the conclusion, that the direct current produces a sensation when it is interrupted, whilst the same phenomenon is developed by the inverse current the instant it commences. The following table may, therefore, very simply express the general law of the action of the current on a living or recently-killed animal, as deduced by Marianini:—

Direct current	when it commences,	contraction of the inferior muscles:
	circuit closed,	nothing;
	when it ceases,	sensations;
Inverse current	when it commences,	sensations;
	circuit closed,	nothing;
	when it ceases,	contractions in the inferior muscles.

(607) Matteucci experimented on a rabbit in the following manner: The animal was secured on a board, and about an inch of its sciatic nerves laid bare and well insulated; it did not appear to suffer much pain, and there was very little hæmorrhage. Underneath the isolated portion of the nerves a long piece of varnished silk was placed, and the nerves were then wiped with unsized paper, to be certain that they were perfectly insulated; one nerve was then submitted to the direct, and the other to the inverse current, the length comprised in the circuit being about two-thirds of an inch A single pair of zinc and copper, or of zinc and platina plates was employed; but with the current from this battery, Matteucci was never able to obtain any well-marked signs of suffering, nor of contractions in the muscles above the irritated nerve, but contractions always took place in the inferior muscles on shutting or on opening either the direct or the inverse current. By continuing for a certain time the action of this current on the same points of the nerve, it was found that contractions of the inferior muscles only take place at the commencement of the *direct* current, and at the interruption of the *inverse*.

In these kind of experiments it is important not to submit the

same nerve to the passage of two contrary currents, one after the other, the passage of an electric current along a nerve being found to modify in some way its excitability, for a current passed in the contrary direction.

(608) When a battery of ten pairs was employed, the rabbit exhibited distinct signs of suffering: at the comencement of the direct current, all the inferior muscles contracted, the rabbit squeaked, contorted its back, and agitated its ears: the same occurred on operating with the inverse current, and always took place at the instant when the two currents ceased. By repeating this experiment on several individuals, it was found in general that the signs of suffering were strongest when the *inverse* current commenced, and that the greatest muscular contractions were those produced at the commencement of the *direct* current. The commencement and interruption of an electrical current of certain intensity, acting on a certain portion of the nervous system, are followed then by the same phenomena, whatever may be the direction of this current through the nerve. By continuing to operate on the same animal, it is easy to see that the phenomena do not always take place in the same manner. The variations which occur commence after a certain time, which is so much the shorter as the current employed is more intense.

(609) By prolonging the action of the current on the living animal, the following differences were noticed: When the direct current was interrupted, the contractions of the inferior muscles became more feeble; whilst they continued in the muscles of the back, the ears were agitated, and the animal frequently uttered cries; when the direct current commenced, the effects were limited to contractions of the inferior muscles. In the inverse current, the contractions of the muscles of the back, the agitation of the ears, and the cry, took place at the commencement, whilst the contractions of the inferior muscles were hardly perceptible. At the interruption of this current, the contractions of the inferior muscles took place, while those of the back and ears, and also the cry, entirely disappeared.

(610) Thus, then, the action of the electric current, which excites the nerves of a living animal, may be reduced to two periods only. In the first period, the excitation of the nerve is transmitted in every direction to its periphery as well as to its centre, at the commencement of the excitation as well as at its interruption, and that independent of the direction of the current in the nerve. In the second period, the excitation of the nerve is conveyed towards its extremities by the direct current at its commencement, or by the inverse current at its interruption: on the contrary, the excitation of the nerve is

transmitted towards the brain when the direct current is interrupted, or when the inverse current commences.

These results may perhaps be expressed in simpler terms: the current during the second period acts in the sense of its direction when it commences, or in the contrary sense when it ceases.

(611) But in what way does the electric current produce contractions in the muscles of the back and head, when this current acts on a nerve which does not ramify through these muscles? How happens it that, in opposition to the generally-received idea, muscular contractions should be produced by the excitation of a nerve in a backward direction?

Matteucci answered this question by the following experiment. He cut the spinal cord of a rabbit arrived at the second period, and found that the contractions of the muscles *above* the excited nerve, only affected those *below*, to the point where the cord had been cut, and which were consequently comprised between the point excited, and the point where the nerve was cut. If the spinal cord be cut altogether at its extremity, there will no longer be found contraction at any point above the excited nerve. The phenomena produced by the passage of the electric current are reduced, then, to the contraction of the inferior muscles, which takes place at the commencement of the direct current, and at the interruption of the inverse current.

(612) It had been shown by Valli that after an animal had ceased to exhibit contractions by the prolonged action of an electric current through its nerve, the contractions may be renewed by causing the current to traverse a portion of the nerve further removed from the brain and nearer the extremities than before. Matteucci verified this with several animals, proving the generality of this principle, viz., that the property of a nerve to excite contractions in the muscles through which it ramifies by the passage of a current, retires towards the extremities of the nerve in proportion as its sensibility diminishes.

(613) By operating with the inverse current, it was found that, in proportion as the sensibility of the nerve became diminished, it became necessary, in order to produce signs of suffering and contractions of the superior muscles, to make the current traverse portions of the nerve *nearer the brain* and further from the extremities; hence the conclusion that the portion of the nerve which, at the introduction of the *direct* current, excites contractions in the muscles, is so much *further* from the central system as the vitality of the nerve becomes less; on the other hand, that the portion of the nerve which, at the introduction of the *inverse* current, excites painful

sensations, approaches *nearer* the central system as the vitality of the nerve becomes less.

When recently-killed rabbits were submitted to the action of a single couple, the inferior muscles contracted at the commencement of the direct current, and at the interruption of the inverse, whatever the direction in which it was applied; but if the current were continued, those contractions alone were obtained which were due to the commencement of the direct and the interruption of the inverse current.

By numerous experiments on frogs, Matteucci convinced himself that the electric current acts only on the nerve, and that there are not, as Marianini objected to Nobili, currents which run at the same time directly, and in an inverse direction, following the ramification of the nerve.

(614) It has been demonstrated by Marianini that contractions of the muscles may be obtained at the interruption of the current without the production of those due to its commencement. He has also shown that the contraction due to the interruption of the current may be obtained without destroying the circuit, but by diverting it from the body of the animal by a better conductor; he has also ascertained that this contraction, which takes place at the interruption of the current, is stronger in proportion as the circuit has been closed a longer time: from his experiments he has drawn the conclusion that during the passage of a current through a nerve in the direction of its ramification, there is one portion of the Electricity which accumulates in this nerve, which at the instant of the interruption of the circuit discharges itself, traversing the nerve in a contrary direction, thus giving rise to the contraction produced by the inverse current at the moment of its interruption. Matteucci, however, objects to this hypothesis, which he thinks inconsistent with the knowledge we possess of the conducting power of nervous substance, and of the manner in which it propagates Electricity through the muscles.

The Action of the Electric Current during its passage across the Nerves and Muscles at the same time on living or recently-killed Animals.

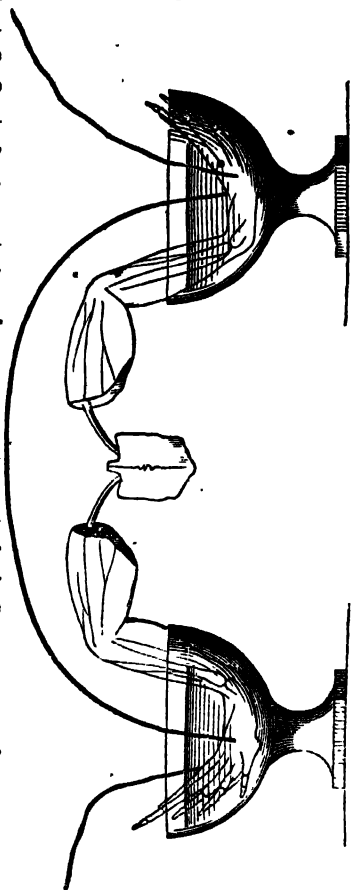
(615) If it were possible entirely to deprive muscle of all nervous filaments, we might hope to discover the action of the electric current on muscular fibre, and thus resolve the question which, since Haller's time, has agitated physiologists; viz.. whether muscular fibre of itself, independently of all external action conveyed through its nerve, is capable of undergoing contraction, and whether the

excitation of the nerve is merely one cause of awakening irritability of the muscle, or if, on the contrary, in order to produce contraction of this muscle, its nerve should be previously irritated.

(616) When a nerve has been for a certain time separated from the central nervous system, it no longer possesses the power of exciting contractions in the muscles through which it ramifies by irritation, or by the action of an electrical current. Matteucci found also that a pile of eight or ten couples produced no action on the sciatic nerves of frogs poisoned with nux vomica, even when the current was passed along the extremities of this nerve, although the same current directed through two points of a muscle of the same animal awakened lively contractions. He hence concludes, 1°. That the property of the living muscular fibre to contract when submitted to external actions, whether directed on the fibre itself or on the nerves ramifying therein, is inherent in itself. 2°. That the motor nerves, irritated in any manner whatever, produce contractions in the muscles in which they ramify, by awakening this inherent property of the muscle. 3°. That these nerves lose this property by the action of narcotic poisons; by their separation at a certain distance from the central parts of the nervous system; by a ligament interposed between the points of the irritated nerve and the muscles; by the continuance of the exciting action, independent of any permanent and substantial alteration in the nerve, which is proved by the property possessed by this nerve of recovering by repose, or by actions which may be called *contrary*, its primitive faculty. 4°. And that, lastly, in order that the irritability of the muscular fibre should continue, it is necessary to preserve in this fibre the simultaneous action of the sensitive and organic nerves, and of the blood by which it is nourished.

(617) From these principles it seems possible to predict, *à priori*, what should be the direction of an electrical current which traverses a mass of muscle, and at the same time all the nervous filaments ramifying therein. If this muscular mass be traversed by the current in a direction parallel to that of the principal nervous trunks distributed therein, it seems evident that the resulting contraction should be stronger than that produced by the same current transmitted in a direction normal to that of the nervous trunks. Indeed, the contraction obtained in the first case is due to that which is proper to the muscular fibre, and to that which is caused in this fibre, by the excitation of the nerves which are traversed by one portion of the current. At the same time, it results that the laws of the contractions excited by the current which traverses a muscular mass, should not, especially while the vitality is still great, differ

from that found to belong to the action of a current limited to the nerve.


Fig. 227.

Matteucci carefully removed all the visible nervous filaments from the thighs of rabbits, from the breasts of pigeons, and from the hearts of several other animals; in this state he passed through them a current from twenty or thirty pairs, and he found that the muscles always underwent coutraction when the circuit was closed. The contraction only lasted for a moment, and seemed to consist in a sort of shortening of the fibres, which caused them to oscillate and knit up; on keeping the circuit closed, the fibres regained their original condition, but again contracted, though more feebly than before, on interrupting the current. The direction of the current had no influence on the result, and if the circuit was kept closed for a considerable time, there was no contraction on interrupting it. Thus, then, visible nervous filaments are not necessary for the production of muscular contractions by the electric current, though much greater effects are produced by a current on a nerve than on a similar breadth of muscular fibre, which might be expected from the very great superiority of conducting power possessed by the muscle.

(618) When an electrical current is passed through a prepared frog, arranged as shown in Fig. 227, where the current is direct for one of the legs and inverse for the other, the following phenomena are observed: At the commencement of the experiment, when the animal is very active, both legs contract, at the commencement as well as at the interruption of the current. As vitality diminishes, only one of the legs contracts; that which is traversed by the direct current contracts at the commencement, and that traversed by the inverse current at the interruption. These results are analogous to

those obtained by operating with the current on the nerve alone, and it is principally to the action of the current which traverses the attached nerve, and ramifies through the muscle, to which the action of the current, which traverses at the same time the nerves and the muscles, is due. It had been noticed by Marianini that, on including two arms in the circuit of a pile of forty or fifty elements, a much stronger shock is experienced in the arm in contact with the negative pole than in that in contact with the positive; now it is easy to see that in this experiment the great nervous trunks of one arm are traversed by the direct current, and those of the other by the inverse current, and as, by experiments on the nerve during its first period of vitality, it has been established that the contractions excited by the commencement of the direct current are always greater than those excited by the commencement of the inverse, it seems that we have only to admit that the contraction produced in a muscle by a current is due, in a great measure, to the action of this current on the nerve which ramifies through the muscle, in order to explain the difference of the intensity of the shocks experienced in the two arms in the above experiment.

The Action of an Electric Current traversing a Nerve normally to its length.

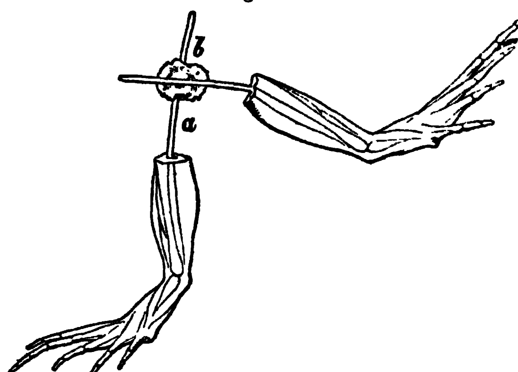


Fig. 228.

Matteucci made the following experiments: Two frogs' legs were prepared, their nervous filaments being preserved, and arranged on an insulated surface, in such a manner that the two nervous filaments crossed at right angles, as shown in Fig. 228, one of the nerves was cut in half, and the two newly-formed extremities were removed about an inch, or an inch and a quarter distant from the nerve of the other leg; the surfaces of the divided nerve were then united by a drop of distilled water. Thus arranged, the points *a* and *b* of the cut nerve were touched with the extremities of a pile composed of a certain number of elements: the current necessarily traversed not only the water, but the interposed nerve also; nevertheless, it was only the leg, the nerve of which was touched by the

extremities of the pile, that contracted, the other leg, the nerve of which was traversed normally by the current, remained at rest; and although, when a great number of couples was employed, contractions were obtained in both legs, the experiment distinctly proves that an electric current which traverses a nerve *normally* to its length, has less power of arousing contractions in the muscles through which it ramifies, than the same current when it traverses the same length of nerve longitudinally.

The Causes which modify the Action of the Electric Current on the Nerves.

(619) 1st. *Alternations of the Current.*—If the current from a certain number of couples be allowed to pass during the twenty-five or thirty minutes through a frog, arranged as in Fig. 228, it is found that on interrupting the circuit, and immediately shutting it again, the animal undergoes no contraction in either case. The time required to produce this effect varies according to the force of the pile and the vitality of the frog. When the animal is reduced to the point at which it ceases to contract, if the poles of the pile be reversed, or if the frog be turned over, so that the current may be transmitted through the limbs in a contrary direction, contractions are obtained anew on shutting the circuit for the limb in which the current is direct, and on interrupting it for the other. If the current be left shut in this second position of the frog, it is found after a certain time (which is always shorter than in the first case) that the animal ceases to contract, whether on opening or on shutting the circuit. This being obtained, it is necessary to reverse anew the position of the frog, or that of the poles of the pile, by which the animal becomes traversed by a current similar to that at the commencement of the experiment; it then contracts anew on shutting the circuit for the limb traversed by the direct, and on interrupting it for the other. These alternations continue for a certain time, growing gradually weaker, and the contractions becoming less, according to the time required for passing from one alternation to the other.

(620) These facts may be simply expressed thus: The current which traverses a motor nerve in a living or recently-killed animal, and which continues to pass along this nerve for a certain time, so modifies its excitability as to render it insensible to its passage as long as it traverses in the same direction, but the excitability of the nerve recovers under the influence of the same current directed in a contrary way: when, then, a nerve has been thus modified by the passage of a current, we may restore to it the excitability it has lost

by sending through it for a certain time a current, directed in a contrary way from that which destroyed its excitability. It has been shown by Marianini that the phenomena above described may be referred entirely to the weakening of the action of the current, directed in a certain direction through the nerves, and to a restoration of this action by a current directed in a contrary way. It seems then, that there exists in the living animal a force which wrestles continually against the property of an electrical current, to weaken the excitability of a nerve through which it traverses in a given direction. It is this force which, in the living animal, is capable of re-establishing the excitability which the nerve has lost, provided it be left for a certain time unacted upon by the current. This has been well established by the experiments of Marianini, and it is an ascertained fact, that *repose* produces in a living animal, the nerves of which have lost their excitability by the action of an electrical current, the same effect as the passage of a current through the nerves in a contrary direction. That the phenomena of alternations are produced entirely by the action of the current on the *nerve* was proved by Matteucci, by passing a current through a piece of muscle, deprived as much as possible of all nervous filaments; he never found, on reversing the position of the extremities of the pile, that the lost power of contraction was regained.

(621) The alternation which is produced in a nerve by the passage of an electrical current, is not independent of its direction relatively to the ramification of the nerve. The direct current destroys the excitability of the nerve much more quickly than the inverse current. The following experiment confirms this: A prepared frog was cut at the union of the two bones of the thigh; it was then placed with its paws in two basins of water, and a current from sixty to eighty couples was passed *directly* for one limb, and *inversely* for the other. In performing this experiment care must be taken that the frog does not leap out of the basins. The contractions continued for some seconds after the closing of the circuit, and it was remarked that the limb traversed by the direct current palpitated for a certain time. After fifteen, twenty, twenty-five, or thirty minutes, according to the degree of vitality in the animal, the water in the two basins was united by a metallic arc, by which a great portion of the current was caused to leave the animal, and the limb traversed by the *inverse* current was found to contract. On removing the arc the contraction ceased. The experiment was repeated several times with a similar result. In order to be still better assured that the nerves of the two limbs have become differently excitable, the frog may be arranged with its nerves in one glass, and

its two feet in a second. Then, on passing the current, one of the limbs is seen to contract, sometimes at the commencement, sometimes at the interruption, according as the current is direct or inverse. In both cases, the limb which contracts is always that which has been traversed by the inverse current in the first experiment. When, by the continued passage of the current only, one of the limbs of the frog has become capable of contraction, the direction of the current may be reversed, so that the limb before traversed by the inverse current shall now be traversed by the direct, and *vice versâ*. It is then found that, by continuing the current for a certain time, the limb which had lost the power of contraction has regained it, although this property has ceased in the other.

(622) It may then be concluded, 1°. That the passage of an electric current across a nerve weakens its excitability in a different manner, according to its direction. 2°. That the passage of the direct current renders the nerve *less* excitable by this same current than the passage of the inverse current.

On submitting two frogs, similarly prepared, for from ten to fifteen minutes, one to the passage of a continuous current of forty-five couples, and the other to the current of a similar pile, the action of which was broken and renewed at short intervals, Matteucci found that the nerves of the animal that had been subjected to the interrupted current were much more weakened than those of the other, and it required a stronger power to excite the former than the latter. Marianini also remarked that of two frogs, one traversed by a continuous current always in one direction, the other by a similar current sent sometimes in one direction and sometimes in the other, the first suffered least in loss of excitability.

(623) 2nd. *Ligature of the Nerve.*—It is a well-known fact, that when in a living or recently-killed animal, a nerve is tied and irritated *above* the ligature, *i. e.*, towards the brain, no contractions ensue, but the animal exhibits signs of suffering; and, on the other hand, that when the nerve is irritated below the ligature, strong contractions of the inferior muscles ensue, without any signs of suffering being evinced. The same general results are obtained when the electrical current is the stimulant employed, but in this case the ligature must be tied tightly, and care must be taken perfectly to insulate the animal operated upon.

(624) 3rd. *Poisons.*—Carbonic acid gas, nitrogen, and chlorine do not weaken the excitability of a nerve submitted to an electrical current; the same may be said of sulphuretted hydrogen. Hydrocyanic acid, on the other hand, possesses a remarkable power of weakening the excitability. It begins by exciting tetanic convulsions

in frogs exposed to its influence; and if they are prepared in this state, and submitted to the action of an electric current, they still contract, especially if the current traverses the nerves and muscles at the same time, or the muscles only. But if the frogs poisoned by this acid be submitted to an electrical current, after they have ceased to exhibit tetanic convulsions, it is very rarely that contractions can be obtained with the current from a single pair passed along the lumbar nerves. A very strong current only produces very feeble contractions, and the excitability altogether disappears after some seconds.

Death by the electric discharge destroys almost entirely the excitability of a nerve by an electric current, but the muscles of the animal do not lose their irritability, for the current still excites contractions in them.

(625) The action of narcotic poisons is curious. The animals are first brought to a state in which the most feeble contraction suffices to agitate their whole frame; they then assume the tetanized condition, during which their limbs become completely stiffened, and after a few minutes all movement ceases. When a frog was submitted to the action of a current in the first of these conditions, contractions were obtained as usual, both at the commencement and at the interruption of the circuit, whatever its direction. During the second period the following phenomena were observed: By operating on the nerve alone, its excitability was found to be weakened. Sometimes the tetanic convulsions were prolonged for some seconds, although the spinal cord was cut. But if, instead of preparing the frog thus tetanized, it was submitted to the passage of a current from a pile of thirty or forty pairs directed along its body, the frog, which an instant before was quite rigid, experienced a smart shock at the commencement of the current, and then, by leaving the circuit shut, the tension of the muscles relaxed. Matteucci in this experiment remarked one difference between the direct and the inverse current. The current directed from the feet to the head excited at the commencement a shock which was weaker than that produced at the commencement of the direct current. This difference between the action of the two currents is in accordance with the general laws already detailed.

Lastly, during the third period of the narcotic poisoning the excitability of the nerve was found either null or nearly so, while the muscular fibre still exhibited contractions when submitted to the electric current.

The Action of the Electric Current on the Nerves of the Senses, and on the Great Sympathetic Nerve.

(626) All the researches in electro-physiology that have been undertaken from the commencement of the science of galvanism to our own time, have proved that the current acting on the nerves of the senses only brings into play the special action appertaining to each of these nerves, a proof that the electric current acts merely as other stimulants.

It was Volta who first demonstrated the existence of a sensation of light when the electrical current traverses any point of the optic nerves. The experiment is easily made by touching with an elementary couple the eye or eyelid and the tongue. Whatever may be the intensity of the current, it is only the sensation of light that is perceived. If we reflect that this sensation may be produced by a very feeble current, and one certainly incapable of exciting a muscular contraction sufficiently strong to shake the eye, it must be admitted that the effect is really to be ascribed to the excitation of the optic nerve. An analogous phenomenon is produced when the current is made to act on the auditory nerves. Volta, on applying the two poles of a pile to his two ears, experienced a *hissing*, a sort of *jerking* noise, which continued all the time the circuit remained closed. According to Ritter, the sensation is only experienced at the commencement of the current, and the noise is sharper at the negative pole.

(627) Again, in the experiment of Sulzer, a taste is experienced when the tongue is traversed by an electrical current. This taste is sourish when a plate of zinc is placed at the base of the organ and a plate of silver on the surface, the two plates being brought into contact; by reversing the position of the plates, the taste becomes alkaline, but this feeble intensity current could not certainly be supposed to decompose the salts dissolved in the saliva A similar sensation was experienced by Volta by taking in his hand a goblet of pewter filled with a moderately alkaline solution, and bringing the base of the tongue into contact with the liquid. It must be remarked that the taste was *sour*, which excludes entirely the idea that it was occasioned by the contact of the alkaline liquor with the tongue. It seems evident, therefore, that the taste excited by the electric current must be owing to the special excitation of the gustatory nerves. In general, then, the effect of a current acting on the nerves of the senses is to awaken the special function of those nerves.

The passage of an electric current through the cardiac and

splanchnique nerves of a living or recently-killed animal increases or arouses the proper motion of the heart and intestines; but what is very remarkable, the phenomenon due to the passage of the current, instead of commencing at the very instant the circuit is closed, only begins after a certain time, and continues for some time after the current has ceased. It must not be forgotten that all other stimulating agents, viz., alkalies, mechanical irritation, heat, applied to the ganglion nerves act in the same manner as the electrical current. The direction of the current is of no consequence in these experiments.

The Differences between the Action of the Electric Current and that of other Stimulants.

(628) It is known that heat, alkalies, or mechanical irritation applied to the motor or sensitive nerves of a living animal occasions at the same time sensation and contractions in the inferior muscles, the excitation of the nerve is then transmitted at the same time to the centre and to the extremities. When, by the continued application of these stimulants, the excitation of the nerve is prolonged, the effects grow weaker, or disappear altogether according to the duration or the intensity of their action.

(629) The electrical current produces the same effects, which, however, very shortly, cease; and an animal may have its nerves traversed by a current for a very long time without exhibiting the least signs; but the moment the current ceases, the phenomena reappear. In proportion as the vitality of the animal becomes weakened, and as the current continues to pass, the resulting phenomena cease to exhibit any analogy to those produced by other stimulants. We have seen that the action of the current differs according to its direction relatively to the ramification of the nerves. Thus the animal experiences a sensation when the *inverse* current commences, and a contraction when it ceases, and the contrary for the *direct* current. It is also known that whatever the stimulant applied to a nerve, it only excites contractions in those muscles through which its branches ramify.

(630) The electrical current, as we have seen, produces in some cases contractions in the superior muscles, and thus exercises an action that may be called retrograde. It has been proved that these phenomena depend on a reflex action through the spinal chord, which only becomes manifest with other stimulants when the animal is placed in particular and abnormal conditions.

A difference even more remarkable than that above cited between the action of stimulants, heat, mechanical and chemical irritations,

&c., and that of Electricity, consists in the power possessed by the current of preserving for a longer time than other stimulants, the excitability of the nerve, and, indeed, of re-establishing in certain cases the excitability it has lost.

(631) The electrical current may traverse for a long time the nerves of a living or a recently-killed animal, without destroying in these nerves the excitability brought into play by a current sent in a contrary direction, and when the nerve, by the prolonged action of the current, has lost this faculty, it may again be restored by the passage of a contrary current.

In whatever manner stimulants may be applied to a nerve, its excitation never fails, and contractions and sensations always follow. The only difference is one of degree, depending on the intensity of the action of the stimulant, and the extent of the nerve submitted to it.

(632) The principal differences indicated by experiment between the action which is excited on the nerves by the electric current, and that excited by other stimulants, may be summed up thus:—

1°. The electrical current, according to the direction in which it traverses a nerve, has *alone* the power of exciting separately, sometimes contractions, sometimes sensations.

2°. The electrical current *alone*, whilst traversing a nerve transversely, produces none of the phenomena due to the excitability of the nerve.

3°. The electrical current *alone* produces no effect when its passage through a nerve is continued.

4°. The electrical current *alone* occasions the continuation of the excitation of a nerve, after its action upon it has ceased.

5°. The electrical current *alone* possesses the power of re-establishing the excitability of a nerve when it is transmitted in a direction contrary to that of the current which had destroyed or weakened this excitability.

6°. The electrical current is of all stimulants that which possesses for the longest time the property of arousing the excitability of a nerve, however weak it may be compared with other stimulants.

The Relation between the Electric Current and the unknown force of the Nervous System: hypothetical views of the nature of this force.

(633) From the conclusions deduced in the last section, it appears that the mode of action of the electric current on the nerves, more

simple than that of other stimulants, is at the same time, in some measure, analogous to the unknown force which works in the nervous system. But can we hence conclude that this unknown force is none other than the electric current? We must be very careful in drawing this conclusion, which unfortunately has been so often readily embraced.

Is there an electrical current in the nerves of a living animal? and can it be applied to the explanation of the functions of the nervous system?

(634) The muscular electric current is a phenomenon which has been proved to derive its origin from chemical actions constituting the nutrition of the muscle. It has also been seen that this current, altogether analogous to that which is produced during the combination of two bodies, only exists between the molecules, and never circulates in these bodies but in particular cases, which have been realized in the muscles of living or recently-killed animals. The nerves have not a direct influence on the existence of this current, and they play no other part than that of a bad conductor, which communicates with certain parts of the muscle.

(635) Matteucci has sought unsuccessfully for an electrical current in the nerves of a living animal. He introduced steel needles into the muscles of living frogs, rabbits, and dogs, in various directions relatively to the muscular fibre, and connected them with the terminal plates of his delicate galvanometer, but could obtain no indications of an electrical current, nor was he more successful with the galvanoscopic frog; he subsequently tried the experiment on the sciatic nerve of a living horse, but without obtaining any trace of an electric current. Indeed, from what is known of the properties and laws of propagation of electricity, it seems impossible to conceive the existence of an electrical current included in the nerves; in order to admit it, such a disposition in the structure of the nervous system as would suffice to form a closed circuit must be proved, but this anatomists have not yet done. Matteucci made the following experiment, in order to ascertain, in an indirect manner, whether the nervous system might readily form a closed circuit for the electric current. He laid bare, in two different points of its length, as far from each other as possible, the sciatic nerve of a living animal: viz. above the thigh to the extremity of the leg. He introduced the limb into a spiral in connection with a smaller spiral containing an iron wire; he then touched the points of the uncovered nerve with the extremities of a pile, in order to send a current through it, but no satisfactory indication of an induced current could be obtained.

(636) The electric current, then, does not exist in the nerves of a living animal: the laws of its propagation require conditions which are not found in the nervous system, and it is certain, that the nervous force, whatever it may be, is not *Electricity*. What relation, then, is there between these two forces? Matteucci's laborious electro-physiological inquiries lead him to the following conclusions: There exists between the electrical current and the unknown force of the nervous system an analogy, which, if it be not susceptible of the same degree of evidence is, however, of the same kind, as that existing between heat, light, and electricity. In all the phenomena of electric fishes, the faculty of producing electricity, with which they are endowed, is under the direct dependence of the nervous system; and there is in these animals a structure, a certain disposition of particular parts of their organism, which, by the agency of the unknown force of the nervous system, enables them to disengage electricity. The parallelism which has been clearly shown to exist between muscular contraction and the electric discharge of fishes, proves distinctly that the two functions depend immediately on those of the nervous system.

(637) The development of Electricity by a crystal of tourmaline when heated, clearly proves the relation between heat and Electricity: a similar relation between the nervous force and Electricity is demonstrated by electric fishes. Electricity is not, however, the nervous force, any more than *heat* is Electricity: the one changes into the other in the one case, by the form of the integrant molecules of the crystal; and in the other, by the structure of the electric organs. In physics we are daily advancing towards a simplification of our hypotheses, or more exactly, towards a single hypothesis serving to explain all the phenomena of heat, light, and Electricity. "What hypothesis, indeed," says Matteucci, "is more worthy of the rank to which it is sought to be elevated, than that of a body which is capable of a variety of different movements, susceptible of transformation from one into the other, and so representing phenomena very different from each other?" The most essential characters of this body, such as the immense rapidity in the propagation of its motions, the transformation of one motion into another, &c., belong to the unknown force of the nervous system, as to Electricity, light, and heat. The relation between two of these movements of *ether*, motions which we have been accustomed to call *imponderables*, becomes much more intimate when not only one of these bodies can be transformed into another, but when each in its turn can be transformed into the first.

(638) Have we this reciprocity between the unknown force of the

nervous system and the electrical current? In a word, is the electrical current transformed into the unknown force of the nervous system?

We know, by experiment, that a nerve traversed by an electric current, in the direction of its length, is excited *in such* a manner as to produce either contraction or sensation. It is necessary for this purpose that the nerve be traversed in the direction of its length; that it shall not have been long separated from the central parts of the nervous system, and that it be not submitted for too long a time to the passage of the current, or to the action of other stimulants.

(639) Heat, mechanical or chemical action, may, like the electric current, arouse the excitability of a nerve, and thus produce contraction and sensation. Are we hence to conclude that these chemical, mechanical, and calorific actions are transformed into an electric current, which alone has the power of exciting a nerve? We should be by no means warranted in drawing such a conclusion, and as it has been proved that the unknown power of the nervous system is not Electricity, so we have no reason to believe that stimulants—viz., heat, chemical or mechanical action, act by producing an electrical current when applied to a nerve.

(640) We may conclude, then, with Müller, that the electrical current, which under certain conditions traverses a nerve, determines in it a change similar to that produced by the unknown force of the nervous system, when it is there excited by external actions, or by the action of the will.

It seems, however, natural and just to suppose that this change effected in the disposition of the elementary organs of a nerve, whether by the act of the will, or by the electric current, or other stimulants, is accompanied in every case by a species of current of the unknown force of the nervous system. This force Matteucci denominates *Ether*, in order to explain by one hypothesis all the phenomena of imponderables, and the analogy of the nervous force with these other forces.

(641) All philosophers agree in the imposibility of explaining the immense rapidity of the propagation of light, of radiant heat, of Electricity, without having recourse to *vibratory motion*. The unknown force of the nervous system is not less rapidly propagated. Ether distributed through all points of the nervous system, as through the whole universe, takes the character of the nervous force, through the modifications introduced in the relative disposition of the molecules by the organization of the nervous substance. The different structure of the nervous fibres, and especially that of their origin and extremities, such as the microscope is now unfolding, may serve to

explain why the molecular change of the nerve which constitutes its excitable state, is less rapid in the ganglionic system than in the other nerves, and why in certain nerves, the excitability is propagated only in a certain direction.

The nervous fluid in this hypothesis is what we suppose heat, electricity, and light to be, viz., a peculiar vibratory motion of ether.

(642) To sum up in a few words these hypothetical views: There is in all parts of the nervous system, as in all bodies in the universe, a *diffused ether*, which in this system may have a particular arrangement, as it is admitted to have in certain crystalline bodies. When the organic molecules of the nerves are from any cause deranged, the ether, or more properly the nervous fluid, is put into a certain motion, which reaching the brain produces sensation, and arriving at the muscles determines contraction. This derangement may be produced by the electric current, by heat, by chemical and mechanical action, as it is naturally by the will; the propagation of the motion will be materially interfered with by any alteration whatever in the structure of the nerve.

(643) Matteucci concludes by offering the following explanation of the action of the electric current on the nerves:—

Let it be admitted that the electrical current, which traverses a nerve in the direction of its length, determines a derangement in the direction of this current, as the experiments of Porrett and Becquerel have proved; let it be admitted that this derangement is accompanied by vibratory movements of the nervous fluid, which are propagated to the extremity of the nerve parallel to the direction of the organic derangement. This current of the nervous fluid produces *sensation* if directed from the extremities towards the brain, and *contraction* if directed from the brain towards the extremities. From this it follows that an electric current traversing a nerve *normally* can produce no phenomenon. The direct current produces contraction when it enters, and sensation when it ceases. The inverse current, on the other hand, produces sensation when it enters, and contraction when it ceases. The phenomena observed during the first period of the vitality of the nerve show that when the organic disposition of the nerve is perfect, its molecules are deranged in every direction by the application of any kind of stimulant, but always more so in the direction of the electric current than in the opposite direction. In proportion as the structure proper of the nerve ceases to be perfect, the phenomena produced by the current are those which take place in the direction in which this force acts with most intensity. Other stimulants produce in the structure of the nerve a derangement of a more permanent nature, and which, unlike that produced by the electric current, does

not cease till the exciting cause is removed. An electrical current which traverses a nerve for a certain time, finishes by permanently deranging its molecules, hence the reason why the prolonged action of the same current ceases after a time to produce its peculiar action on a nerve. A current in the contrary direction will bring back the molecules of the nerve into their former condition, and restore to them their capability of being excited by a current in the same direction as the first. The passage of an electrical current through a nerve in a different direction, the successive interruption of this current, and its greater intensity, are the causes most likely to produce a permanent derangement in the structure of a nerve.

Du Bois Reymond's experiment of producing an electric current by muscular contraction.

(644) If it be granted that the muscular current is developed in the muscle itself, which Du Bois Reymond's researches have abundantly proved, it can scarcely be doubted that it is in a state of circulation during the life of the animal. It has been seen (598) that on connecting the transverse and longitudinal section a current appears; but such a connection exists naturally in the body, and hence the inference is a fair one that such currents are perpetually present, and that the current which we perceive in the galvanometer is, in fact, but one of the branches of this pre-existing current. A live frog was disposed with its two legs dipping into two vessels filled with salt and water, and connected with either extremity of the galvanometer. Now, it was long ago shown by Nobili, that a current exists in the frog directed *from the foot, upwards;* but in the case before us, we have two such currents, one at each foot, which meet at the junction of the limbs, annul each other, and consequently produce no effect on the galvanometer. But suppose one of these currents to be enfeebled, while the other retains its full strength, the result will be that the excess of the latter current should produce a deflection. Du Bois Reymond accordingly severed the *ischiotic* nerve of one of the frog's legs, and thus deprived the limb of all power of motion; he then poisoned it with strychnia; strong convulsions followed, the uninjured limb contracted violently, its muscular current was thereby diminished, and *the current of the other limb was immediately exhibited by the galvanometer.*

(645) Du Bois Reymond immediately tried the experiment on himself. He placed the first finger of his right hand in one vessel, and the corresponding finger of his left hand in the other; but instead of cutting his nerves, as in the case of the frog, he suffered

the left arm to remain at rest, and contracting the other forcibly, produced a deflection of the needle; when the left arm was contracted and the right one suffered to remain at rest, the needle was deflected in the opposite direction. The current always proceeded *from the hand of the contracted arm to the shoulder*: but remembering the fact that it is the *excess of the* current of the motionless arm which is here observed, we are led to the inference, that in the normal state of the arm the direction of the current is *from the shoulder to the hand.*

(646) The publication of this result created a considerable sensation; it was received by many with doubt and misgiving. Some eminent men undertook to repeat the experiment: their results were negative, and for a time the opinion was predominant that Du Bois Reymond was in error, and that M. Humboldt, who took a conspicuous part in the affirmative side of the question, had suffered himself to be misled. But if the conditions of the experiment be rigidly fulfilled, the experiment will always succeed.*

(647) *Electric fishes*:—There are some remarkable instances of the generation of Electricity in living animals, to whom the power seems principally to be given as a means of defence. Of these animals the Raia Torpedo appears to have been noticed at a very early period, since we find a description of its properties in the writings of Pliny, Appian, and others. It inhabits the Mediterranean and North Seas; its weight when full grown is about eighteen or twenty pounds.

It is frequently met with also upon the Atlantic coast of France, as well as along our southern shores, especially in Torbay, where it attains a great size. It is taken by the *trawl* in company with its cogenitors, the rays. At Malta it is known by the name of *Haddayla*, a term which has reference to its benumbing power: in France it is called *La Tremble*, and with us it has various designations, as the cramp or numb fish, and the Electric Ray. Dr. Davy has recently reduced the four previous recognised species of torpedo into two species, viz.: the torpedo *diversicolor*, and the torpedo *oculata*, a term having reference to certain markings on the back which have been likened to eyes.

(648) The generic characters of the torpedo (Henry Letheby) are: The disc of the body is nearly circular; the pectoral fins large; the two dorsal fins are placed so far back as to be on the tail; the surface of the body is smooth; the tail short and rather thick, and the mouth armed with small sharp teeth.

* It was several times repeated by Dr. Du Bois Reymond during his lectures on Electrophysiology, delivered at the Royal Institution in the spring of 1855.

It is an ovo-viviparous animal, the young being matured in their descent along the oviduct, where they are retained for several months; and during this detention, the yolk bag disappears and the fish are perfected; the electrical organs also become gradually developed. Dr. Davy thinks these are formed from matters which are absorbed by the bronchial filaments; an opinion which he deduces from the fact of these not attaining such great size and length in other rays, while they also drop off when the organs are complete.

(649) When touched the torpedo communicates a benumbing sensation, and by repeated contacts gives a series of electric shocks. In the Philosophical Transactions, 1773 and 1775, there are accounts of some experiments of Mr. Walsh on this animal. He placed a living torpedo on a wet napkin, and formed a communication through five persons, all of whom were insulated. The person at one extremity touched some water in which a wire, proceeding from the wet napkin, terminated; the last person in the series having a similar mode of communication with a wire, which at intervals could be brought into contact with the back of the animal. In this manner shocks were communicated to the five, and afterwards to eight persons. Mr. Walsh could not succeed in affecting the electroscope, or in obtaining a spark by this electricity. But he observed that every time the animal gave a shock, which was not generally perceptible beyond the finger with which it was touched, a contortion of the body followed, as if the animal were anxious to make its escape; its eyes were also depressed, so that he could tell by observing the eyes, when the animal attempted to make a discharge, even upon non-conducting bodies. Mr. Cavendish constructed an artificial torpedo of wood, connected with glass tubes and wires, and covered with a piece of sheep-skin leather. To render the effect of this instrument more like that of the animal, with regard to the difference of the shock in and out of the water, it was necessary to substitute thick leather in the place of the wood; and with this improvement the apparatus succeeded admirably. In air the sensation of the shock was experienced at the elbows; but under water it was confined chiefly to the hands. On touching this artificial torpedo under water, a shock was obtained as powerful as if it had been touched by both hands. Being touched under water with two metallic spoons, it gave no shock; but in air, the shock was very strong. Cavendish also made an estimate between the strength of his artificial torpedo and that dissected by Hunter, with reference to surface. His own battery consisted of seventy-six feet of coated surface, and he calculated that the animal retained a charge fourteen times as great as that of the battery, or was equivalent to one thousand and sixty-four feet of coated glass.

(650) In the Philosophical Transactions for 1773, there is a detail of the anatomical structure of this curious fish, from the pen of the celebrated Hunter.*

"The nerves," he says, "inserted into each electric organ, arise by three large trunks from the latter and posterior parts of the brain. The first of these, in its passage outwards, turns round a cartilage of the cranium, and sends a few branches to the first gill, and to the anterior part of the head, and then passes into the organ at its anterior extremity. The second trunk enters the gills between the first and second openings, and furnishes it with small branches, passing into the organ near the middle. The third trunk, after leaving the skull, divides into two branches, which pass to the electric organ through the gills, one between the second and third openings, the other between the third and fourth, giving small branches to the gill itself. These nerves having entered the organs, ramify in every direction between the columns, and send in small branches on each partition, where they are lost.

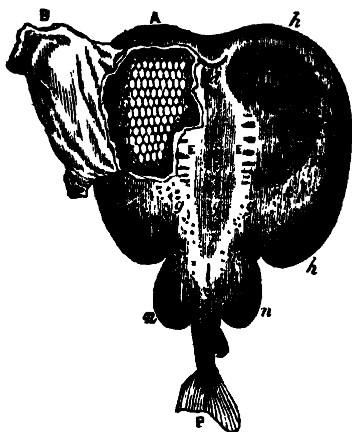
"The magnitude and number of the nerves bestowed on these organs, in proportion to their size, must, on reflection, appear as extraordinary as the phenomena they afford. Nerves are given to parts either for sensation or for action. Now, if we except the more important senses of seeing, hearing, smelling, and tasting, which do not belong to the electric organs, there is no part, even of the most perfect animal, which, in proportion to its size, is so liberally supplied with nerves, nor do the nerves seem necessary for any sensation which can be supposed to belong to the electric organs. And with respect to action, there is no part of any animal with which I am acquainted, however strong and constant its natural actions may be, which has so great a proportion of nerves. If, then, it be probable that these nerves are not necessary for purposes of sensation or action, may we not conclude that they are subservient to the formation, collection, or management of the electric fluid? especially as it appears evident, from Mr. Walsh's experiments, that the will of the animal does absolutely control the electric powers of the body, which must depend upon the energy of the nerves."

Fig. 229† represents a female *torpedo*, the skin B having been flayed from the under surface of the fish to show the electric organs A. The nostrils in the form of a crescent are shown at *e*, and the mouth, having also a crescent form opposite the nostrils, at *d*; the mouth is furnished with several rows of small hooked teeth. The

* For a detailed account of the anatomy of this fish, see also Proceedings of the Electrical Society, p. 512.

† Encyclopædia Britannica, art. Electricity.

Fig. 229.



branchial apertures are shown at E, five being on each side. E is the place of the heart; *g g g* the place of the anterior transverse cartilages; *h h* the exterior margin of the great lateral fin; *i* its inner margin on the confines of the electrical organ; *l* the abdomen; *m m* the place of the posterior transverse cartilages which is single, united with the spine, and sustains the smaller lateral fins *n n* on each side; *o* is the anus, and *p* the fin of the tail. Each organ is about five inches long and about three inches broad at the anterior end, and half an inch at the posterior extremity. Each organ consists wholly of perpendicular columns reaching from the upper to the under surface of the body, and varying in their lengths according to the thickness of the parts of the body where they are placed. The longest column is about $1\frac{1}{2}$ inches, the shortest about a $\frac{1}{4}$th of an inch, and their diameter about $\frac{2}{10}$ths of an inch. The figures of the columns are irregular hexagons or pentagons, and sometimes have the appearance of being quadrangular or cylindrical. The number of columns in the fish examined by John Hunter was 470 in each organ; but in a very large fish, $4\frac{1}{2}$ feet long and weighing 73 pounds, the number was 1,182 in each organ. The number of partitions in a column one inch long was 150.

(651) A great number of experiments on the electricity of the torpedo were made by MM. Gay Lussac and Humboldt. The fish were taken in the Gulf of Naples. Though their power cannot be compared with that of the gymnotus, a person accustomed to electric shocks can with difficulty hold in his hands a torpedo of twelve or fourteen inches, in possession of all its vigour. The shock is most powerful when the animal is raised above the surface of the water. It moves its pectoral fins convulsively every time it emits a stroke, whereas the gymnotus gives its strongest shocks without making any movement. A shock is not necessarily felt on touching the fish; it must be irritated, thus proving the action to depend on the will of the animal; but it can give a long series of shocks with great rapidity, and the stroke is felt on touching it with a single finger. M. Gay Lussac noticed this remarkable difference between the torpedo and the gymnotus, that, whereas, the latter could give its shocks through

an iron rod several feet long, the former may be touched with impunity with any conducting substance; direct contact with the electrical organ of the fish is indispensably necessary for the reception of a shock.

(652) When the torpedo is placed on a metallic plate, of very little thickness, so that the plate touches the inferior surface of the organs, the hand that supports the plate never feels any shock, though another insulated person may excite the animal, and the convulsive movement of the pectoral fins may denote the strongest and most reiterated discharges. If, on the contrary, a person support the torpedo placed upon a metallic plate with the left hand as in the foregoing experiment, and the same person touch the superior surface of the electrical organ with the right hand, a strong shock is then felt in both arms. The sensation is the same when the fish is placed between two metallic plates the edges of which do not touch, and the person applies both hands at once to these plates. The interposition of one metallic plate prevents the communication if that plate be touched with one hand only, while the interposition of two metallic plates does not prevent the shock when both hands are applied. In the latter case, it cannot be doubted that the circulation of the fluid is established by the two arms. M M. Gay Lussac and Humboldt carried the torpedo with impunity between two plates of metal, and felt the strokes it gave, only at the instant when they ceased to touch each other at the edges.

(653) The electric phenomena of the torpedo have been minutely studied by Matteucci. (*Traite des Phénomènes Electro-Physiologiques des Animaux.*) The following is a brief *resumé* of his conclusions: He alludes to the extraordinary diffusion of the electric discharge of the torpedo in a liquid. A tub, five feet across, was filled with salt water, and a torpedo held in the hand close to one side, a prepared frog being suspended at the other extremity. Every time the fish discharged, the frog contracted violently; an effect which could not be produced by a pile of very great force, especially if it be considered that a great portion of the current circulates through the hand, and that another large portion must circulate by the surface itself of the animal.

Movements, sometimes scarcely sensible, are perceived in the body of the torpedo when it gives an electric discharge; and sometimes these movements are very considerable. By the following experiment, however, it was proved that the fish can discharge without any change in the volume of its body taking place: A moderate-sized female torpedo (5½ in.) was introduced into a jar of salt water, a prepared frog being laid upon its body. The jar was accurately closed, and a glass tube of small diameter was fixed into the top.

After having well luted the mouth, the glass was filled with water till the fluid rose in the tube to a certain height. The torpedo from time to time gave electric discharges, and the frog contracted, but the level of the water in the tube remained unaltered.

(654) The torpedo has not the power of directing its discharge through any particular object. When the fish is very lively, and its discharges strong, shocks are felt wherever the fish is touched; but when it has become weak, the shocks are not felt over the whole body, but only in the neighbourhood of the electric organs.

By means of his galvanometer, Matteucci deduced the following general laws relating to the distribution of Electricity in the body of the torpedo:—

1°. All the dorsal parts of the organ are positive to all the ventral parts.

2°. Those points of the organ on the dorsal face which are above the nerves which penetrate this organ, are positive, relatively to other points of the same dorsal face.

3°. Those points of the organ on the ventral face, which correspond to those which are positive on the dorsal face, are negative, relatively to other points of the same ventral face.

(655) By passing the discharge from the torpedo through a spiral of copper wire enclosing a steel needle, the needle was magnetized in such a manner as to show the direction of the current to be from the back to the under part of the belly. To measure the intensity of the discharge, Linari employed the electro-magnetic balance of Becquerel, and on comparing with this instrument the discharge of a moderate-sized torpedo with that of a battery of nine jars, exposing a coated surface of ninety-four square inches, the former was found to be much more intense than the latter.

The same philosopher obtained marked heating effects, by passing the discharge of the fish along a thermo-electric couple.

Electro-chemical decomposition had been effected by Dr. John Davy. Matteucci repeated his experiments with success, and, by employing an apparatus something similar to that used by Mr. Gassiot, in his experiments on the gymnotus at the Adelaide Gallery, he succeeded in obtaining brilliant sparks.

The Causes which influence the Electric Discharge of the Torpedo.

(656) Among external causes may be mentioned the mass and temperature of the water, and the degree of irritation to which the animal is exposed. The activity of the electric function is proportional to the circulation and respiration of the animal. Matteucci found that a torpedo that was giving discharges, consumed more

oxygen than another that was quiet; and on introducing a small and very feeble fish, that could scarcely give any sensible shocks, under a receiver filled with oxygen gas, it became agitated, and gave five or six strong discharges before it died. When the electric organ of the torpedo is destroyed, either by the action of mineral acids, or by boiling water, the fish loses its power of giving discharges, but, before its power fails, it gives several strong shocks. If one of the electric organs be rapidly separated from the living fish, the discharge may be obtained by irritating the nerves, which proves that the integrity of the circulation of the blood in the organ is not necessary for the production of the electric power.

(657) In order to destroy entirely the power of the fish to give discharges, it is necessary to cut all four of the nerves leading to the electric organ; when one or more nerves are cut, the discharge is confined to those parts of the organ among which the uncut nerves ramify. The discharge may also be prevented by tying the nerves; but even where the nerves are cut, discharges may be obtained by irritating them, unless the nervous trunks have previously been acted on by caustic potash. Of the four lobes of the brain, the fourth only is found to actuate the electric current; it is hence called the electric lobe. Strong discharges and muscular contractions ensue on touching it; if it be destroyed, all electric power is lost to the animal, although the rest of the brain remains untouched.

(658) The action of electric currents on the nerves of the electric organs may be thus stated:—

1°. That in the first period after death, during which the vitality of the nerves is still very great, the electric current, direct or inverse, invariably produces the discharge, both at its commencement and at its interruption.

2°. In the following period of vitality, the discharge is only produced by the commencement of the direct current, and by the interruption of the inverse.

(659) The following are the general conclusions drawn by Matteucci from the results of his researches on the torpedo:—

1°. The electric discharge of the torpedo, and the direction of this discharge, depends on the will of the animal, which, for this function, has its seat in the brain.

2°. The Electricity is developed by the organ of the torpedo, commonly called the *electric* organ, under the influence of the will.

3°. Every external action which is directed on the body of the living torpedo, and which determines the discharge, is transmitted by the nerves of the irritated point to the electric lobe of the brain.

4°. Every irritation directed on the fourth lobe, or its nerves, pro-

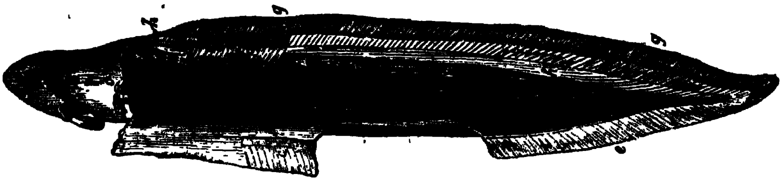
duces no other phenomenon than the electric discharge. This lobe and its nerves may therefore be called *electric lobes and nerves*, as we say, *nerves of sensation, nerves of motion, nerves of organic life.*

5°. The electric current which acts on the lobe or its electric nerves, produces only the discharge of the organ, and this action of the currrent remains longer than that of all other stimulants.

(660) The gymnotus is another fish possessed of electrical properties; it is a native of the warmer regions of America and Africa, inhabiting large rivers, especially those of Surinam. In Africa it chiefly occurs in the branches of the Senegal. It is so named from the absence of the dorsal fin. There are several species, all inhabiting fresh-water lakes and rivers; but one species alone is electrical. In general aspect it very much resembles an eel,—the body is smooth, without scales (a peculiarity of all electrical fishes), a long ventral fin extends from just behind the head to the very extremity of the tail; around the mouth are many papillæ lodged in crypts, which are merely mucous glands. The mouth is armed with sharp teeth, and projecting into it are numerous fringes, which, from their vascularity, doubtless serve a purpose in respiration. The œsophagus is short, terminating in a capacious stomach with thick rugose parietes. The rest of the alimentary canal is short, doubled on itself, and terminates in the *cloaca*, which is situated in the mesial line, a few inches from the under jaw. The whole cavity of the abdomen is not more than seven inches long, and contained, in the female specimen examined by Dr. Letheby, besides the alimentary canal, ovaries filled with ova of a bright orange colour, the heart, the liver, and upper part of the air bladder. The rest of the animal is made up of the electrical organs and muscles of progression, together with an air sac, which runs beneath the spine the whole length of its body. The Gymnotus was first described by Richer, in 1677, and its anatomical structure by Mr. Hunter, in the 63rd and 65th volumes of the Philosophical Transactions. The electric organs consist of alternations of different substances, and are most abundantly supplied by nerves; their too frequent use is succeeded by debility and death. That these organs are not essential to the animals, is proved by their thriving after they have been removed.

Fig. 230 represents a copy of Hunter's engraving of the gymnotus, in which the skin is removed to show the structure: *a* represents the lower surface of the head; *c* the cavity of the belly; *b* the anus; *e* the back, where the skin remains; *g g* the fin along the lower edge of the fish; *e e* the lateral muscles of this fin, removed and laid back with the skin to expose the small organs; *l* part of the muscle left in its place; *f f* the large electrical organ; *h h h* the small electrical

Fig. 230.



organs; *m m m* the substance which separates the two organs; and *n* the place where the substance is removed. These organs occupy nearly one-half of the part of the flesh in which they are placed, and form more than one-third of the whole fish. There are two pairs of electrical organs of different sizes, and placed on different sides; the large one, *f*, occupies the whole of the lower and lateral part of the fish constituting the thickness of its fore-part, and extending from the abdomen to near one end of the tail, where it terminates nearly in a point. The two organs are separated at the upper part by the muscles of the back, at the lower part by the middle partition, and by the air-bag at the middle part. The lesser organ stretches along the lower edge of the fish, and nearly as far as the other, terminating almost insensibly near the end of the tail. The two small organs are separated from each other by the middle muscle and by the bones in which the fins are articulated. The large organ may be seen by merely removing the skin, which adheres to it by a loose cellular membrane; but in order to see the small organ, the long row of small muscles which move the fin must be removed. The electrical organs consist of two parts, viz., flat partitions or septa, and thin plates or membranes intersecting them transversely. The septa are thin parallel membranes, stretching in the direction of the fish's length, and as broad as the semi-diameter of the animal's body. The septa vary in length, some of them being as long as the whole body. In a fish two feet four inches long, the distance of the septa was nearly half an inch; and in the broadest part of the organ, which was one and a quarter inch, there were thirty-four septs. In the small organs the septa have a somewhat serpentine direction. They are only the fiftieth of an inch distant, and there are fourteen septa in the breadth of the organ, which is half an inch. The very thin plates which intersect the septa have their breadth equal to the distance between any two septa. There is a regular series of these plates from one end of any two septa to the other end, 240 of them occupying a single inch.*

* The anatomical structure of the gymnotus has more recently been studied by Dr. Letheby. See his paper in the Proceedings of the London Electrical Society, p. 367.

(661) The gymnoti abound in the large rivers of South America, the Orinoco, the Amazon, and the Meta; but the force of the currents and the depth of the water prevent them from being caught by the Indians. They see these fish less frequently than they feel shocks from them when swimming or bathing in the river. In the Llanos, particularly in the environs of Calabozo, between the farms of Morichal and the Upper and Lower Missions, the basins of stagnant water and the confluents of the Orinoco (the Rio Guarico and the *Canos* Rastro, Berito, and Paloma), are filled with electric eels.

(662) The following graphic account of the capture of this fish is taken from Humboldt's Travels to the Equinoctial Regions of America (Bohn's edition, vol. ii. p. 114): "We wished at first to make our experiments in the house we inhabited at Calabozo; but the dread of the shocks caused by the gymnoti is so great and so exaggerated among the common people, that during three days we could not obtain one, though they are easily caught, and we had promised the Indians two piastres for every strong and vigorous fish. This fear of the Indians is the more extraordinary as they do not attempt to adopt precautions in which they profess to have great confidence. When interrogated on the effect of the *tembladores*, they never fail to tell the Whites that they may be touched with impunity while you are chewing tobacco. This supposed influence of tobacco on animal electricity is as general on the continent of South America as the belief among mariners of the effect of garlic and cotton on the magnetic needle.

"Impatient of waiting, and having obtained very uncertain results from an electric eel which had been brought to us alive, but much enfeebled, we repaired to the Cano de Bera, to make our experiments in the open air and at the edge of the water. To catch the gymnoti with nets is very difficult, on account of the extreme agility of the fish, which bury themselves in the mud. The Indians, therefore, told us that they would fish with horses. We found it difficult to form an idea of this extraordinary manner of fishing, but we soon saw our guides return from the savannah, which they had been scouring for wild horses and mules. They brought about thirty with them, which they forced to enter the pool.

"The extraordinary noise caused by the horses' hoofs makes the fish issue from the mud, and excites them to the attack. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organization presents a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the pool closely; some

climb up the trees, the branches of which extend horizontally over the surface of the water. By their wild cries and the length of their reeds, they prevent the horses from running away and reaching the bank of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electric batteries. For a long interval they seem likely to be victorious. Several horses sink beneath the violence of the invisible strokes which they receive from all sides in organs the most essential to life; and stunned by the force and frequency of the shocks, they disappear under the water. Others panting, with mane erect and haggard eyes expressing anguish and dismay, raise themselves and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water, but a small number succeed in eluding the active vigilance of the fisherman. These regain the shore, stumbling at every step, and stretch themselves on the sand, exhausted with fatigue, and with limbs benumbed by the electric shocks of the gymnoti.

"In less than five minutes two of our horses are drowned. The eel being five feet long, and pressing itself against the belly of the horses, makes a discharge along the whole extent of its electric organ. It attacks at once the heart, the intestines, and the cœliac fold of the abdominal nerves. It is natural that the effect felt by the horses should be more powerful than that produced upon man by the touch of the same fish at only one of his extremities. The horses are probably not killed, but only stunned. They are drowned from the impossibility of rising amid the prolonged struggle between the other horses and the eels.

"We had little doubt that the fishing would terminate by killing successively all the animals engaged; but by degrees the impetuosity of this unequal contest diminished, and the wounded Gymnoti dispersed. They require a long rest and abundant nourishment to repair the galvanic force which they have lost. The mules and horses appear less frightened: their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry, the Indians feel no shock in raising the fish into the air. In a few minutes we had five large eels, most of which were but slightly wounded. Some others were taken, by the same means, towards evening."

(663) These eels measured from five feet to five feet three inches in length. They were of a fine olive-green colour, the under part of the head being yellow, mingled with red. Two rows of small yellow spots were placed symmetrically along the back from the head to the

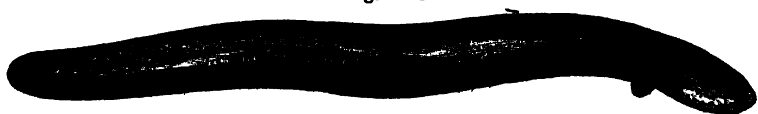
end of the tail; each spot contained an excretory aperture, in consequence of which the skin of the animal was constantly covered with a mucous matter, which conducts Electricity twenty or thirty times better than pure water. The shock from a very large and strongly-irritated gymnotus, Humboldt describes as being "more dreadful than that from a large Leyden jar." By imprudently placing both of his feet on an eel just taken out of the water, he received a stroke which affected him during the rest of the day with a violent pain in the knees, and in almost every joint. The sensation caused by feeble shocks was analogous to that painful twitching produced by the contact of two heterogeneous metals with a wounded surface.

(664) The electric action of the fish depends entirely on its will. It does not keep its electric organs always charged, and it can direct its action towards the point where it feels itself most strongly irritated. When two persons insulated, or otherwise, hold each other's hands, and only one of these persons touches the fish with the hand, either naked or armed with metal, the shock is most commonly felt by both at once. Occasionally, however, in the most severe shocks, the person who comes into immediate contact with the fish alone feels them. Humboldt could not obtain a spark from the body of the fish by irritating it for a long time during the night in perfect darkness. It had been stated by Schilling that the gymnotus approaches the magnet involuntarily. Humboldt did not find this to be the case, neither could he discover any phenomena of attraction or repulsion by employing the most delicate electrometer.

(665) The gymnoti are held in dread and detestation by the natives. They furnish, indeed, when divested of their electric organs pretty good food, but they destroy other fish, and are generally the sole inhabitants of the ponds and pools in which they are found. All the inhabitants of the waters dread their society; they are avoided even by alligators and lizards; tortoises and frogs speedily desert the pools in which they reside. It became necessary to change the direction of a road near Urituco, because the electric eels were so numerous in one river that every year they killed a great number of mules as they forded the river with their burdens. *(Humboldt.)*

(666) A fine specimen of the gymnotus (Fig. 231 being a correct

Fig. 231.



representation) was for some time in the possession of the proprietors of the Gallery of Practical Science in Adelaide Street. It was brought

to this country by Mr. Porter, and deposited in the Gallery in August, 1838, where it remained in a healthy and vigorous condition till March 14th, 1842, when it died from the effects of a rupture of a blood-vessel consequent upon expansion of the ovarium.

The length of this fish was forty inches. At first it was fed with blood, which was nightly put into the water, which was changed for fresh water in the morning; subsequently it was supplied with small fish, such as gudgeons, carp, and perch, one of which, on an average, it consumed daily.

(667) It may not be uninteresting to give a brief account of some of the experiments made by Dr. Faraday with this fish, the results having afforded every proof of the identity of its power with common Electricity.*

1st, *Shock.*—This was very powerful when one hand was placed on the body near the head, and the other near the tail. When the *dry* hands grasped metallic conductors in contact with the fish, scarcely any shock was felt; but when the hands were wetted, smart shocks were experienced.

2nd, *Galvanometer.*—A pair of collectors were thus constructed: a plate of copper, eight inches long by two inches and a half wide, was bent into a saddle shape, that it might pass over the fish, and enclose a certain extent of the back and sides, and a thick copper wire was brazed to it, to convey the electric force to the experimental apparatus; a jacket of sheet caoutchouc was put over the saddle, the edges projecting at the bottom and the ends; the ends were made to converge so as to fit in some degree the body of the fish, and the bottom edges were made to spring against any horizontal surface on which the saddles were placed. The part of the wire liable to be in the water was covered with caoutchouc.

By causing the fish to send a powerful discharge through these collectors, a galvanometer of no great delicacy being included in the circuit, a deflection of the needle amounting to 30° was produced; the deflection was constantly in a given direction, the electric current being always from the anterior parts of the animal through the galvanometer wire to the posterior parts. The former were, therefore, for the time, externally positive, and the latter negative.

(668) *Making a Magnet.*—When a little helix, containing twenty-two feet of silked wire wound on a quill, was put into the circuit, and an annealed steel needle placed in the helix, the needle became a magnet, and the direction of its polarity in every case indicated a current from the anterior to the posterior parts of the gymnotus through the conductors used.

* Experimental Researches, 15th Series.

(669) *Chemical Decomposition.*—Polar decomposition of iodide of potassium was obtained by moistening three or four folds of paper in the solution, placing them between a platinum plate and the end of a platinum wire, connected respectively with the two saddle conductors. Whenever the wire was in conjunction with the conductor at the fore part of the gymnotus, iodine appeared at its extremity; but when connected with the other conductor, none was evolved at the place on the paper where it before appeared. By this test Dr. Faraday compared the middle part of the fish with other portions before and behind it, and found that the conductor A, which being applied to the middle, was negative to the conductor B applied to the anterior parts, was, on the contrary, positive to it when B was applied to places near the tail. So that, within certain limits, the condition of the fish externally at the time of the shock appears to be such that any given part is negative to other parts anterior to it, and positive to such as are behind it.

(670) *Evolution of Heat.*—The experiments were not decisive on this point, as might be expected; the instrument employed was a Harris's thermo-electrometer.*

(671) *Spark.*—The electric spark was first obtained in the following manner: A good magneto-electric coil, with a core of soft iron wire, had one extremity made fast to the end of one of the saddle collectors, and the other fixed to a new steel file; another file was made fast to the end of the other collector. One person then rubbed the point of one of these files over the face of the other, whilst another person put the collectors over the fish, and endeavoured to excite it to action. By the friction of the files contact was made and broken very frequently; and the object was to catch the moment of the current through the wire and helix, and by breaking contact *during the current* to make the Electricity sensible as a spark. The spark was obtained four times: a revolving steel plate, cut *file-fashion* on its surface, was afterwards substituted for the lower file; and for the upper file, wires of iron, copper, and silver, with all of which the spark was obtained.

In subsequent experiments the spark was obtained *directly*

* Mr. Gassiot, however, by employing an electrometer of peculiar construction, having, instead of one straight wire, two separate wires, one of fine silver and the other of fine platinum, made under the personal inspection of Sir William Harris, has succeeded in developing the heating power of the gymnotus. In the first experiment (made on the 21st of May, 1839), the circuit was completed through the platinum wire, when the liquid in the electrometer rose *one* degree.

In the second experiment the circuit was completed through the silver wire, when the liquid rose *two* degrees.

between fixed surfaces, the inductive coil being removed, and only short wires used. The apparatus employed was a glass globe, through the upper cap of which a copper wire, slightly bent at its lower extremity, and carrying a slip of gold leaf, was passed; a similar wire terminating with a brass ball within the globe was passed through the lower cap. The gold leaf and brass ball were brought into all but actual contact, and when the wires were connected with the saddle collectors, and the fish provoked to discharge a current of Electricity, the gold leaf was attracted to the ball, and a spark passed.*

(672) When the shock is strong, it is like that of a large Leyden battery charged to a low degree, or that of a good voltaic battery of perhaps one hundred or more pairs of plates, of which the circuit is completed for a moment only; and great as is the force of a single discharge, the fish is able to give a double, and even a triple shock, with scarcely a sensible interval of time. Dr. Faraday endeavoured to form some idea of the *quantity* of Electricity, by connecting a large Leyden battery with two brass balls above three inches in diameter placed seven inches apart in a tube of water, so that they might represent the parts of the gymnotus to which the collectors had been applied; but to lower the intensity of the discharge, eight inches in length of six-fold wetted string were interposed elsewhere in the circuit, this being found necessary to prevent the easy occurrence of the spark at the ends of the collectors when they were applied to the water near to the balls, as they had been before to the fish. Being thus arranged, when the battery was strongly charged and discharged, and the hands put into the water near the balls, a shock was felt much resembling that from the fish; and though the experiments have no pretension to accuracy, yet as the tension could be in some degree imitated by reference to the more or less ready production of a spark, and after that, the shock be used to indicate whether the quantity was about the same, Dr. Faraday thought that it may be concluded that a single medium discharge of the fish was at least equal to the Electricity of a Leyden battery of fifteen jars,

* It was Mr. Gassiot, we believe, who first obtained attractions of gold leaves in the following manner:—

A common glass tumbler, having two small holes drilled on each side, was inverted on a wooden stand: two copper wires, with small brass balls attached, were passed through the holes; to each ball a strip of gold leaf was fixed about 1 inch long and $\frac{1}{8}$ of an inch wide: the leaves being placed parallel to each other, were then approximated to within about $\frac{1}{30}$ or $\frac{1}{40}$ of an inch. On making contact with the eel, the leaves were not only attracted, but were actually fused, scintillating in the most beautiful manner.

containing 3,500 square inches of glass coated on both sides, and charged to its highest degree.

(673) Numerous other interesting experiments were made by Dr. Faraday with this fine specimen of the gymnotus, from all of which it was rendered evident that all the water, and all the conducting matter around the fish, through which a discharge circuit can in any way be completed, is filled at the moment with circulating electric power, and this state might be easily represented by drawing the lines of inductive action upon it. In the case of a gymnotus surrounded equally in all directions by water, these would resemble generally in disposition the magnetic curves of a magnet, having the same straight or curved shape as the animal, *i. e.*, provided he, in such cases employed, as may be expected, his four electric organs at once. That all the conducting matter around the fish is filled at the moment with circulating electric power, was proved by the fact, that a number of persons all dipping their hands at the same time into the tub, the diameter of which was forty-six inches, received a shock of greater or less intensity according as they were more or less favourably situated with regard to the direction of the current.

(674) The gymnotus can stun and kill fish which are in very various positions to its own body. Dr. Faraday describes the behaviour of the eel on one occasion when he saw it eat, as follows: A live fish, about five inches in length, caught not half a minute before, was dropped into the tub. The gymnotus instantly turned round in such a manner as to form a coil enclosing the fish, the latter representing a diameter across it: a shock passed, and there in an instant was the fish struck motionless, as if by lightning, in the midst of the water, its side floating to the light. The gymnotus made a turn or two to look for its prey, which having found, he bolted, and then went searching about for more. Living as this animal does in the midst of such a good conductor as water, it seems at first surprising that it can sensibly electrify anything; but in fact it is the very conducting power of the water which favours and increases the shock by moistening the skin of the animal, through which the gymnotus discharges its *battery*. This is illustrated by the fate of a gymnotus which had been caught and confined for the purpose of transmission to this country. Notwithstanding its wonderful powers, it was destroyed by a *water-rat*, and when we consider the perfect manner in which the body of the rat is insulated, and that even when he dives beneath the water not a particle of the liquid adheres to him, we shall not feel surprised at the catastrophe.

(675) The gymnotus appears to be sensible when he has shocked

an animal, being made conscious of it, probably, by the *mechanical impulse* he receives, caused by the spasms into which he is thrown. When Dr. Faraday touched him with his hands, he gave him shock after shock; but when he touched him with glass rods, or insulated conductors, he gave one or two shocks felt by others having their hands in at a distance, but then ceased to exert the influence, as if made aware it had not the desired effect. Again, when he was touched with the conductor several times for experiment on the galvanometer, &c., and appeared to be languid or indifferent, and not willing to give shocks, yet, being touched by the hands, they, by convulsive motion, informed him that a sensitive thing was present, and he as quickly showed his power and willingness to astonish the experimenter.

(676) In these most wonderful animals, then, we behold the power of converting the *nervous* into the *electric* force. Is the converse of this possible? Possessing, as we do, an electric power far beyond that of the fish itself, is it irrational or unphilosophical to anticipate the time when we shall be able to re-convert the electric into the nervous force? Seebeck taught us how to commute heat into Electricity, and Peltier, more recently, has shown us how to convert Electricity into heat. By Œrsted we were shown how to convert the electric into the magnetic force, and Faraday has the honour of having added the other member of the full relation, by re-acting back again and converting magnetic into electric force.

(677) The following are the experiments suggested by Faraday, as being rational in their performance and promising in anticipation:—

1°. If a gymnotus or torpedo has been fatigued by frequent exertion of the electric organs, would the sending of currents of similar force to those he emits, or of other degrees of force, either continuously or intermittingly, in the same direction as those he sends forth, restore him his powers and strength more rapidly than if he were left to his natural repose?

2°. Would sending currents through, in the contrary direction, exhaust the animal rapidly?

3°. When, in the torpedo, a current is sent in the natural direction, *i. e.*, from below upwards, through the organ on one side of the fish, will it excite the organ on the other side into action? or if sent through in the contrary direction, will it produce the same, or any effect on that organ?

4°. Will it do so if the nerves proceeding to the organ or organs be tied? and will it do so after the animal has been so far exhausted by previous shocks, as to be unable to throw the organ into action in any, or in a similar, degree of his own will?

(678) It is for the physiologist to pursue this inquiry: to him it belongs to connect these two branches of physical philosophy, a minute acquaintance with practical anatomy being quite as indispensable as a thorough knowledge of the laws of Electricity. "Never, however," as Daniell observes, "was there a more tempting field of research, or a higher reward offered for its successful cultivation, than that which is presented by *animal Electricity*."

(679) In the autumn of 1839, Professor Schoenbein of Bâle, went through a series of experiments with the London gymnotus, and obtained results entirely in accordance with those just described. One fact, however, was observed during the decomposition of iodide of potassium which greatly surprised those who witnessed it. At the instant when the paper, impregnated with the iodide, was put in communication with the fish, a visible spark was observed: this spark did not occur every time, but in an exceptional manner, although the experiments were repeated in circumstances as similar as possible. "So far as I myself have been able to observe," says Schoenbein, "we never obtain a spark, either at the moment when we complete the circuit of a galvanic pile, by means of an electrolytic body, or at the moment when this latter is put out of the action of the current. I dare not, then, express an opinion upon the nature and cause of the phenomenon just mentioned, especially as I fear to decide whether the spark really occurred at the opening of the circuit, or at the instant of its being closed."

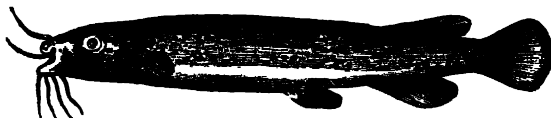
(680) In summing up some exceedingly interesting remarks on the electrical powers of the gymnotus,* Schoenbein declares it to be his opinion that the true cause of the phenomena is still completely obscure, and must neither be sought for in the physical or chemical constitution, nor in a fixed organization of certain parts of the animal; but that there exists, without our being able at present to determine how, an intimate connection between the vital actions dependent on the will of the fish, and the physical phenomena which these vital actions produce. Until we know more exactly the nature of Electricity, we shall be unable to detect this intimate relation which exists between electric and vital action, until we know whether Electricity is only a particular condition of what we call matter, or whether it arises from particular vibrations of the ether, or, in fine, whether like gravity it must be regarded as a primitive and specific force of nature. So long as we are without an exact idea of what Electricity is, the different modes of its development will, of course, be incomprehensible to us, and we shall scarcely be able to say any-

* Proc. Lond. Elect. Soc. p. 133.

thing upon the cause of animal Electricity, even though anatomists and physiologists should have very carefully studied the structure of the fish, and should have made us most intimately acquainted with all its fibres and its most minute nerves."

(681) Fig. 232 is an engraving of another electrical fish, the

Fig. 232.



Silurus Electricus. It is about twenty inches long, and is found in the Senegal, the Niger, and the Nile. Its flesh is an article of food, and its skin is used as a medicine. The shock is distinctly felt when it is laid on one hand, and touched by a metallic rod held in the other. Its electrical organs, according to M. Geoffrey, are much less complicated than those of other electrical fishes. Other known electrical fishes are the *Tetraodon Electricus*, found in cavities of the coral rocks in Johanna, one of the Canary Islands, and also in the American seas; the *Trichiarus Electricus*, which inhabits the Indian seas: several others have been met with, but not hitherto accurately described.

Electricity of Plants.

(682) It was long ago announced by Pouillet (*Pogg. Ann.* xi. 430), that during the process of vegetation Electricity was excited, but the conclusions of this Electrician were not confirmed by the experiments of Reiss (*Pogg. Ann.* lxxix. 288). Becquerel more recently (*Compt. Rend.* xxxi. 633) observed various electric actions in growing plants, which, however, he ascribed to a chemical origin. The latest investigations are those of Wartmann (*Bibliothèque Universelle de Genèva*, Dec. 1850) and of Buff (*Phil. Mag.*, *N. S.*, vol. vii., p. 122). The following are the conclusions to which the first arrived after an investigation continued for two years:—

1.° Electric currents are to be detected in all parts of vegetables but those furnished with isolating substances, old bark, &c., &c.

2.° These currents occur at all times and seasons, and even when the portion examined is separated from the body of the plant, as long as it continues moist.

3.° In the roots, stems, branches, petioles, and peduncles, there exists a central descending, and a peripherical ascending current: Wartmann calls them axial currents.

4.° On connecting, by means of the galvanometer, the layers of

the stem where the liber and the alburnum touch, either with the most central parts (pith and perfect wood) or with the most external parts (young bark), lateral currents passing from these layers to surrounding parts have been detected.

5.° In the leaf the current passes from the lamina to the nerves, as well as to the central parts of the petiole and the stalk.

6.° In the flowers the currents are feeble. They are very marked in the succulent fruits, and in some kinds of grain; the currents from fruits proceeding in most cases from the superficial parts to the adjacent organs. The strength of the current depends on the season, they are greatest in the spring, when the plant is bathed in sap.

7.° Currents can also be detected proceeding from the plant to the soil, which is thus positive with relation to it, and currents are also manifested when two distinct plants are placed in the circuit of the rheometer.

(683) These experiments have been repeated and confirmed by Becquerel (*Comptes Rendus*, Nov. 4th, 1850). He ascertained particularly the determination of electrical currents from the pith and the wood to the bark, which shows that the earth in the act of vegetation continually acquires an excess of positive Electricity and the parenchyma of the bark, and a part of the wood an excess of negative Electricity, which is transmitted to the air by means of the vapour of exhaled water; and the opposite electric states of vegetables and the earth give reason to think that from the enormous vegetation in certain parts of the globe, they must exert some influence on the electric phenomena of the atmosphere.

(684) Buff objects to the conclusions of Wartmann and Becquerel on the ground that the platinum wires employed by these electricians exhibit, when in contact with the liquids in the plants, different degrees of electric excitation, and the sum or the difference of these actions must of necessity change the quantity, and perhaps, also, the quality, of the original action due to the plant alone. Hence he considers that the question, whether plants, in their natural condition and during their free growth, discharge Electricity, is not answered by these experiments.

The method he adopted was altogether different. Two beakers were filled to the depth of half an inch with mercury, and then with water; the plant to be examined had its roots placed in one and its leaves in the other. Two platina wires, hermetically sealed into glass tubes, exposing a few lines at the end, were immersed in the mercury of each beaker, and connected with the galvanometer. The following general results were obtained: " The roots and all the inte-

rior parts of the plants filled with sap, are in a permanently *negative* condition, while the moist or moistened surface of the fresh branches, leaves, flowers, and fruits are permanently *positively* electric." The direction of the current was always from the roots to the leaves, and (in parts of plants) from the place of severance to the external surface of the leaves; even scratching a leaf had the effect of determining a current from the wounded to the entire portion.

CHAPTER XI.

THERMO-ELECTRICITY.

In the year 1821, Professor Seebeck, of Berlin, made the capital discovery that electric currents may be excited in all metallic bodies by disturbing the equilibrium of temperature, the essential conditions being that the extremities should be in opposite states as regards temperature. His apparatus was remarkably simple: it consisted of two different metals (antimony and bismuth were found the most efficient), soldered together at their extremities and formed into frames of either a circular or a rectangular figure. Electricity was excited by the application of heat to the places at which the metals were united, and was evinced by the disturbance of the astatic magnetic needle balanced on a point, situated between the extremities. Fig. 233 shows the disposition of the apparatus. The best effect is produced by heating one of the compound corners by the flame of a spirit-lamp, and cooling the opposite corner by wrapping a few folds of filtering paper round it and moistening it with ether. Pouillet's arrangement, Fig. 234, consists of a stout cylindrical bar of bismuth bent twice at right angles with soldered copper wires attached to the ends communicating with a contrivance on the stand for completing the electric circuit in any direction.

Fig. 233.

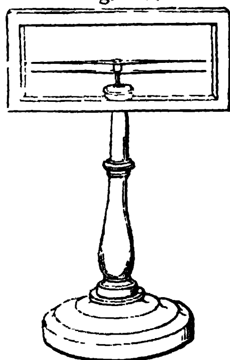


Fig. (235) shows another mode of arranging the metals: *c c* is a

Fig. 234.

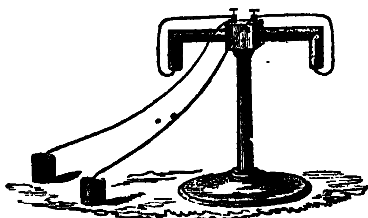


Fig. 235.

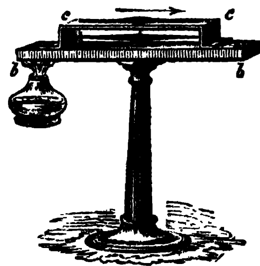
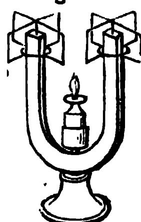


plate of copper, the ends of which are bent at right angles and soldered to the plate of bismuth *b b*; a magnetic needle is balanced in

the interior of the circuit. The apparatus being placed in the magnetic meridian, one of the junctions of the metals is heated by a spirit-lamp, the needle is immediately deflected showing the passage of an electric current in the direction of the arrow head, *i. e.*, from the hot to the cold end.

In Fig. 236 two frames, composed of platinum and silver wires, are represented delicately poised on the poles of a horse-shoe magnet, a spirit-lamp being placed between them, the flame of which causes the circulation of thermo-electric currents in the wires, as evinced by their rotation round the poles of the magnet.

Fig. 236.



(685) Experiments have shown that the thermo-electric properties of metals have no connection with their galvanic relations or their power of conducting heat or Electricity; neither do they accord either with their specific gravities or atomic weights. In forming a thermo-electric series, it is desirable to combine an extreme positive with an extreme negative metal.

The subjoined table by Professor Cumming exhibits a series. When any of these metals are heated at their point of junction, electrical currents are developed in such a manner that each metal becomes positive to all below and negative to all above it in the test; and the reverse order is observed if the point of junction be cooled.

Thermo-electric series.	Volta series by acids.	Series of conductors— of Electricity.	of heat.
Galena	Potassium	Silver	Silver
Bismuth	Barium	Copper	Gold
Mercury }	Zinc	Lead	Tin
Nickel }	Cadmium	Gold }	Copper
Platinum	Tin	Brass }	Platinum
Palladium	Iron	Zinc }	Iron
Cobalt }	Bismuth	Tin	Lead
Manganese }	Antimony	Platinum	
Tin	Lead	Palladium	
Lead	Copper	Iron	
Brass	Silver		
Rhodium	Palladium		
Gold	Tellurium		
Copper	Gold		
Silver	Charcoal		
Zinc	Platinum		
Cadmium	Iridium		
Charcoal }	Rhodium		
Plumbago }			
Iron			
Arsenic			
Antimony			

(686) Many trials have been made to construct thermo-electric piles, that would operate in a manner similar to the admirable instrument for which we are indebted to the genius of Volta. It appears that the labours of MM. Nobili and Melloni were first crowned with the greatest success. These two philosophers constructed conjointly a thermo-electric pile, with which they made some very interesting experiments on radiant heat. The pile, Figs. 237, 238, was composed of fifty small bars of bismuth and antimony, placed parallel side by side, forming one prismatic bundle thirty millimetres* long, and something less in diameter. The two terminal faces were blackened. The bars of bismuth, which succeeded alternately to those of antimony, were soldered at their extremities to the latter metal, and separated at every other part of their surfaces, by some insulating substance, such as silk or paper. The first and last bars had each a copper wire which terminated in a peg of the same metal passing through a piece of ivory, fixed in a ring. The space between this ring and the elements of the pile was filled with some insulating substance. The loose extremities of the two wires were connected with the ends of the wire of a galvanometer which indicated by the motion of the needle when the temperature of the farthest face of the pile was above or below that of the other.

Fig. 237.

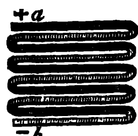
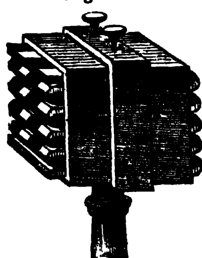
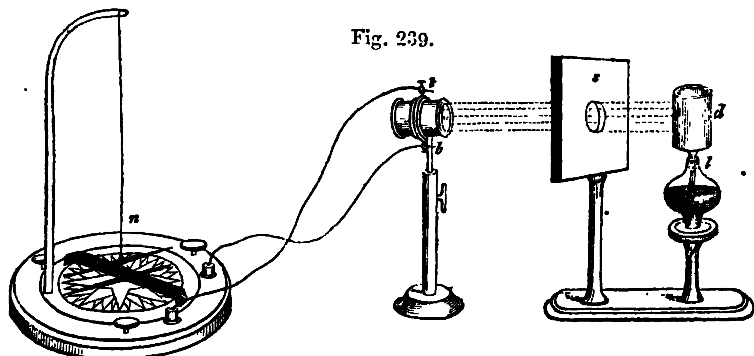


Fig. 238.



In Fig. 239 is a representation of this thermo-electric pile, as arranged by Melloni for his experiments on radiant heat: *t*, a brass cylinder containing the compound bars, having the wires from the

Fig. 239.

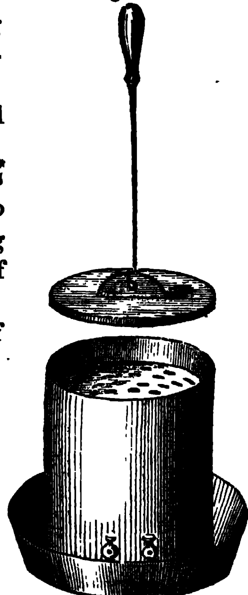


poles connected with the galvanometer, which, as the thermo-current

* A metre is 39·37 inches; a decimetre 3·9 inches; a centimetre 0·39 inches; and a millimetre 0·039 inches.

has but little intensity, should consist of a few coils of pretty stout copper wire. The extremities of the bars at *b* being exposed to any source of radiant heat, such as the copper cylinder *d* heated by the lamp *l*, while the temperature of the other extremity of the bars remains unchanged, a current of Electricity passes through the wires from the poles of the pile and causes the needle of the galvanometer to be deflected. The quantity of Electricity circulating increases in proportion to the difference of the temperature of the two ends; that is, in proportion to the quantity of heat falling on *b*, and the effect of this current of Electricity on the needle, or the deviation produced, is proportional to the quantity of Electricity circulating, and consequently to the heat itself—at least Melloni found this correspondence to be exact through the whole arc from zero to twenty degrees, when the needle is truly astatic. The delicacy of this apparatus is such, that, according to Nobili, it is capable of measuring a difference of temperature of $\frac{1}{2200}$ of a degree.

Fig. 240.



(687) Thermo-piles are now constructed by soldering together at their alternate edges bars of antimony and bismuth, with squares of card-board or thick paper intervening to prevent contact, the terminal metals being furnished with wires for the convenience of connection.

(688) Fig. 240 is a representation of Locke's convenient form of the thermo-electric battery. It is composed of from 30 to 100 series of bars of antimony and bismuth soldered together at their extremities, and placed in a metallic cylinder which is then filled with plaster of Paris, leaving merely the extremities of the bars exposed. The first bar of bismuth is connected with one mercury cup, and the last antimony bar with the other cup. The instrument is put in action by placing it in a vessel of ice, and then laying the hot iron plate on the top.

Fig. 241.

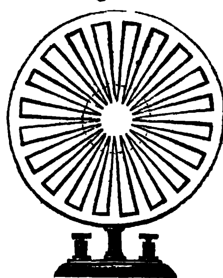


Fig. 241 is Professor Cumming's stellar-form thermo-electric composite battery. It is composed of a series of forty pairs of iron and copper wires, formed in radial lines on a circular card-board. The battery is excited by the radiation of a heated body, placed

opposite the central junctions, while, at the same time, the exterior parts of the wire-frame are screened from the influence of the calorific rays by a polished reflecting screw.

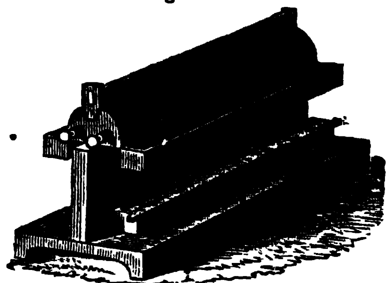

Fig. 242.

Fig. 242 is Professor Dove's composite thermo-battery for constant currents. It consists of a horizontal half-cylinder of wood covered with 100 pairs of iron and platinum wires, which touch its periphery in such a manner that all the iron wires are situated in a right-handed ball, the platinum wires in a left-handed spiral. The elevation of temperature at the junction of the united pairs is effected by the oil or water contained in the oblong trough being heated by a spirit lamp.

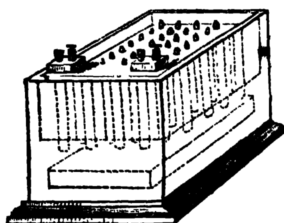
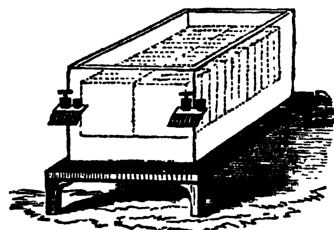
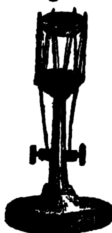

Fig. 243.

Fig. 243 represents Van der Voort's thermo-electric combination, consisting of eighteen pairs of bismuth and antimony prismatic rods united alternately by solder, and fixed in a mahogany box by plaster of Paris, leaving the two extremities of the metals exposed to be acted on by unequal temperatures. To use it, the lower end is placed in a freezing mixture, and boiling oil or water is placed on the top.


Fig. 244.

Watkins's massive thermo-electric pile is shown in Fig 244. It consists of an association of square bismuth and antimony plates, alternately soldered together, so as to form a composite battery, mounted in a frame with the upper and lower junctions of the metals exposed. When either ends are slightly elevated or depressed, in regard to temperature, the electric current is established, and with the radiation of red hot iron at one extremity and ice at the other, all the ordinary electric phenomena, such as the spark, heat, electro-magnetic rotations, chemical action, &c., are developed.

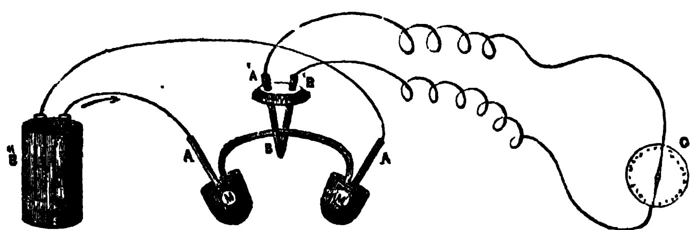

Fig. 245.

(689) A very ingenious hygrometer, founded on thermo-electric principles, was invented by Peltier, Fig. 245. It consists of a series of slender bars of antimony

and bismuth, arranged alternately in the form of a crown, and metallically united in pairs: the extreme bars are connected by copper wires, with binding screws attached to the stem of the support. A platinum dish containing distilled water is placed on the points of the compound bars. An electrical current is developed by the reduction of temperature, occasioned by the evaporation of the water in the capsule, and the deflection of the galvanometer caused thereby, may be taken as a measure of the rapidity of evaporation, and hence, of the hygrometric state of the atmosphere.

(690) It was discovered by Peltier that heat is *absorbed* at the surface of contact of bismuth and antimony in a compound metallic conductor when Electricity traverses it from the bismuth to the antimony, and that heat is generated when the current traverses it in a contrary direction. This is referred to by Joule (*Phil. Mag.* 1843), as showing how it may be proved that when an electrical current is continuously produced from a purely thermal source, the quantities of heat evolved electrically in the different homogeneous parts of the circuit are only compensations for a loss from the junctions of the different metals, or that when the effect of the current is entirely thermal, there must be just as much heat emitted from the parts not affected by the source, as taken from the source. Adie (*Phil. Mag.* vol. v. p. 197,) denies the production of cold under any circumstances by the electrical current, but the following ingenious experiment of Tyndall, who has recently re-investigated the subject (*Phil. Mag.* vol. iv. 1852, p. 419,) seems quite conclusive on the point:—

Fig. 246.



B is a curved bar of bismuth with each end of which a bar of antimony A A is brought into close contact; in front of the two junctures are chambers hollowed out in cork, and filled with mercury. A current is sent from the cell B in the direction indicated by the arrow; at M it passes from antimony to bismuth, and at M′ from bismuth to antimony. Now, if Peltier's observation be correct, we ought to have the mercury at M warmed, and that at M′ cooled, by the passage of the current. After three minutes' circulation, the

voltaic circuit was broken, and the thermo-test pair A′ B′ dipped into M′, the consequent deflection was 38°; and the sense of the deflection proved that at M′ heat had been *absorbed*. The needles were brought quickly to rest at 0°, and the test pair was dipped into M, the consequent deflection was 60°, and the sense of the deflection proved that at M heat had been *generated*. The system of bars represented in the figure being imbedded in wood, the junction at M was cooled slowly, and would have taken a quarter of an hour at least to assume the temperature of the atmosphere. The voltaic current was reversed, and three minutes' action not only absorbed all the heat at M, but generated cold sufficient to drive the needle through an arc of 20° on the negative side of 0°.

It was shown by Lenz (*Pogg. Ann.* vol. xliv. p. 341), that if two bars of bismuth and antimony be soldered across each other at right angles, and they be touched with the conducting wires of the battery, so that the positive current will have to pass from the bismuth to the antimony, a cold sufficient to freeze water may be produced; for if a cavity be excavated at the point of contact, and a drop of water previously cooled to nearly 32° be placed therein, *it will rapidly become ice.*

(691) The first account we have of the production of a spark from a thermo-electric apparatus, appears in a communication from Professor Wheatstone to the London and Edinburgh Philosophical Magazine (vol. x. p. 414). The following is the simple statement:—

The Cav. Antinori, Director of the Museum at Florence, having heard that Professor Linari, of the University of Siena, had succeeded in obtaining the electric spark from the torpedo by means of an electro-dynamic helix and a temporary magnet, conceived that a spark might be obtained by applying the same means to the thermo-electric pile. Appealing to experiment, his anticipations were fully realized. No account of the original investigations of Antinori has reached, we believe, this country, but Professor Linari, to whom he early communicated the results he had obtained, immediately repeated them, and published the following additional observations of his own, in *L'Indicatore Sanese*, No. 50, Dec. 13, 1836.

1°. "With an apparatus consisting of temporary magnets and electro-dynamic spirals, the wire of which was five hundred and five feet in length, he obtained a brilliant spark from a thermo-electric pile, of Nobili's construction; consisting only of twenty-five elements, which was also observed in open day-light.

2°. "With a wire eight feet long, coiled into a simple helix, the spark constantly appeared in the dark, on breaking contact, at every interruption of the current; with a wire fifteen inches long, he saw

it seldom, but distinctly; and with a double pile, even when the wire was only eight inches long. In all the above-mentioned cases, the spark was observed only on breaking contact, however much the length of the wire was diminished.

3°. "The pile, consisting merely of these few elements, readily decomposed water, within such restricted limits of temperature as those of ice and boiling water. Short wires were employed, having oxidable extremities; the hydrogen was sensibly evolved at one of the poles.

4°. "A mixture of marine salt moistened with water, and of nitrate of silver, being placed between two horizontal plates of gold, communicating respectively with the wires of the pile, the latter, after having acted on the mixture, gave evident signs of the appearance of revivified silver on the plate which was next the antimony.

5°. "An unmagnetic needle, placed within a close helix, formed by the wire of the circuit, was well magnetised by the current.

6°. "Under the action of the same current, the phenomenon of the palpitation of mercury was distinctly observed."

(692) The principal results here stated were verified by Professor Wheatstone; he employed a thermo-electric pile, consisting of thirty-three elements of bismuth and antimony, formed into a cylindrical bundle, three-fourths of an inch in diameter, and one inch and one-fifth in length; the poles of this pile were connected by means of two thick wires, with a *spiral of copper ribbon*, fifty feet in length, and one inch and a-half broad, the coils being well insulated by brown paper and silk. One face of the pile was heated by means of a red-hot iron, brought within a short distance of it; and the other face was kept cool by contact with ice. Two stout wires formed the communication between the poles of the pile and the spiral, and the contact was broken when required in a mercury cup, between one of the extremities of the spiral and one of these wires. Whenever contact was thus broken, a *small but distinct spark was seen;* it was visible even in day-light. Professors Daniell, Henry, and Bache assisted in the experiments, and were all equally satisfied with the reality of the appearance.

At another trial, Professor Wheatstone obtained the spark from the same spiral, connected with a small pile of fifty elements, on which occasion Dr. Faraday and Professor Johnston were present. On connecting two such piles together, so that the similar poles of each were connected with the same wires, the same was seen brighter.

(693) Some experiments on the chemical action of the thermo-electric pile, were made *anterior* to those above described, by Professor

G. D. Botto, of the university of Turin, with a different arrangement of metals; his experiments are published in the Bibliothèque Universelle for September, 1832. His thermo-electric apparatus was a metallic wire or chain, consisting of twenty pieces of platinum wire, each one inch in length, and one-hundredth of an inch in diameter, alternating with the same number of pieces of soft iron wire, of the same dimensions. This wire was coiled as a helix round a wooden rule, *eighteen* inches long, in such a manner that the joints were placed alternately at each side of the rule, being removed from the wood at one side to the distance of four lines. Employing a spirit-lamp of the same length as the helix, and one of Nobili's galvanometers, a very energetic current was shown to exist; acidulated water was decomposed, and the decomposition was much more abundant, when copper instead of platinum poles were used; in this case, hydrogen only was liberated. The current and decomposition were augmented when the joints were heated more highly. Better effects were obtained with a pile of bismuth and antimony, consisting of one hundred and forty elements, bound together into a parallelopiped, having for its base a square of two inches, three lines, and an inch in height.

(694) For developing Electricity of feeble intensity it is always best to employ a flat copper ribbon coil. Mr. Watkins found that he could always show a larger spark with it than with an elongated wire coil and large temporary magnet; and that the snapping noise accompanying the thermo-electric spark was more discernible.

Mr. Watkins arranged one of the extremities of his pile of strong sheet copper, cut like a comb, and covered with soft solder; and when the moveable extremity of the flat coil is passed over the comb, and the thermo-electric pile in action, bright sparks were seen every time the moving part of the coil broke the circuit by leaving a tooth of the comb. With a pile consisting of thirty pairs of bismuth and antimony, one inch and a-half square, and one-eighth thick, with the radiation from red-hot iron at one extremity, and ice at the other, a soft iron electro-magnet under the inductive influence of the Electricity thus generated, supported ninety-eight pounds weight. The same experimentalist states that he has thermo-electric piles in his possession, varying from fifteen to thirty pairs of metallic elements, which give brilliant sparks by simply pouring hot water on one end, while the other end is at the temperature of the atmosphere; and that sparks are exhibited by the same piles, when the temperature is reduced at one end by the aid of ice, while the other end is at the temperature of the surrounding air. In order to effect the decomposition of water, Mr. Watkins employed a massive thermo-battery, with pairs of bismuth and antimony, a small

apparatus for the decomposition of water, of the ordinary description, and an electro-dynamic heliacal apparatus. The primary coil of wire was ninety feet long, and when the thermo-electric current simply pervaded this coil, he did not notice any disengagement of the gases; but as soon as the contrivance for making and breaking battery-contact was put in action, then an evolution of the gases took place, while at the same time powerful shocks were received from the secondary coil of wire one thousand five hundred feet long.

(695) From the interesting discovery made by Faraday, of the high conducting power of certain fused salts for voltaic Electricity, Dr. Andrews was led to imagine that thermo-currents may be excited by bringing them into contact with metals, and he succeeded in verifying this conjecture in the following manner:—

(696) Having taken two similar wires of platina (such as are used in experiments with the blowpipe), and connected them with the extremities of the copper wire of a delicate galvanometer, he fused a small globule of borax in the flame of a spirit-lamp on the free extremity of one of the platinum wires, and introducing the free extremity of the other wire into the flame, he brought the latter, raised to a higher temperature than the former, into contact with the fused globule; the needle of the instrument was instantly driven with great violence to the limit of the scale. The direction of the current was from the hotter platinum wire through the fused salt to the colder wire. A permanent electrical current in the same direction was obtained by simply fusing the globule between the two wires, and applying the flame of the lamp in such a manner, that, at the points of contact with the fused salt, the wires were at different temperatures.

(697) Dr. Andrews also succeeded in obtaining chemical decompositions by this peculiar thermo-current. A piece of bibulous paper, exposing on each side a surface of one-fourth of a square inch, was moistened with a solution of the iodide of potassium, and laid on a *platinum plate*, which was in metallic connexion with one of the platinum wires used in the previous experiments. The extremity of the other platinum wire in contact with the globule, was applied to the surface of the bibulous paper, and the flame of the lamp was so directed, that the latter was the colder of the wires, between which the globule of borax, or carbonate of soda, was fused. The platinum plate in this arrangement, therefore, constituted the *negative pole*, and the extremity of the wire applied to the bibulous paper the *positive pole.** Accordingly when the circuit was completed, an abundant

* Dr. Andrews found that by using a *platinum wire*, exposing an extensive surface, as one pole of a voltaic pair, and a fine wire of the same metal as the other, he could effect the decomposition of water; when, by employing a pair of

deposition of iodine occurred beneath the platinum wire. When a similar wire of platinum was substituted for the plate on the negative side, the effect was either *none* or scarcely perceptible.

(698). Dr. Andrews next formed a compound arrangement, by placing a series of platinum wires on supports, in the same horizontal line, and fusing between their adjacent extremities small globules of borax. The globules and wires were exactly similar to those that are used in blow-pipe experiments. A spirit-lamp was applied to each globule, so as to heat unequally the wires in contact with it; and the corresponding extremity of each wire being preserved at the higher temperature, the current was transmitted in the same direction through the whole series. By connecting the extremities of four cells of this arrangement with an apparatus for decomposing water, in which the opposite poles consisted of a thick platinum wire, and a guarded platinum point (both being immersed in dilute sulphuric acid), very minute bubbles of gas soon appeared at the guarded point, and slowly separating from it, ascended through the liquid. They were obtained in whichever direction the current was passed, but rather more abundantly when the point was negative and the wire positive. With only two cells, similar bubbles formed in a visible manner on the guarded point, but in such exceedingly small quantity that they did not separate from it. With an arrangement containing twenty cells, a doubtful sensation was communicated to the tongue, when the poles were applied to it: but no spark was visible, although the current was passed through a helix of copper wire, surrounding a bar of iron, and the contact was broken with great rapidity, by means of a revolving apparatus. It is necessary to observe, however, that the lamps were unprotected, and that it was impossible to render the flames of such a number of spirit-lamps, burning near each other, so steady, as to heat at the same moment,

similar platinum plates, or similar fine wires as poles, he could obtain no such result. After the evolution of gas had ceased, he finds that an additional quantity is procurable, either by increasing the surface of the broad pole, or by removing it, and heating it to redness, or by reversing the direction of the current. Dr. Andrews accounts for this, by supposing that when the poles exposed on both sides equal surfaces, the *gases were dissolved in the nascent state by the surrounding liquid;* but when the polar surfaces were unequal, the solution of the gas being greatly facilitated by the broader pole, the element of water separated there was dissolved, while the other element was disengaged in the gaseous state at the wire, which served as the opposite pole. In order, therefore, to discover, in case of difficulty, whether an electrical current is capable of decomposing water, or other substances, it is necessary to employ poles, having very unequal surfaces; and this will be effected in the most perfect manner by opposing a thick wire, or plate of platinum, to one of Wollaston's guarded points (211).

in the required manner, all the globules and wires. With an enlarged and more perfect apparatus, Dr. Andrews thinks a spark might be obtained.

(699) Hence it appears that an electrical current is always produced when a fused salt, capable of conducting Electricity, is brought into contact with two metals, at different temperatures, and that powerful chemical affinities can be overcome by this current *quite independently of chemical action.* The direction of the current is not influenced by the nature of the salt or metal, being always from the hotter metal through the fused salt to the colder; its intensity is inferior to that of the hydro-electric current developed by platinum and zinc plates, but greatly superior to that of the common thermo-electric currents, and is capable of decomposing, with great facility, water and other electrolytes. Dr. Andrews found also that currents were produced *before* the salt becomes actually fused, but that their direction no longer follows the simple law before enunciated, but varies in the most perplexing manner, being first from the hot metal to the cold, then with an addition of heat, from the cold to the hot; and again, with a second addition of heat, from the hot to the cold.—(See Dr. Andrews' paper, in vol. x., and page 433, of the L. and E. Phil. Mag.)

(700) Since the phenomena of thermo-Electricity seem to account, in a satisfactory manner, fort he general distribution of Electricity and magnetism over the earth, the interest attached to this peculiar development of the subtile agent we have been engaged with, is exceedingly great. That the earth may be considered as a great magnet, the phenomena of the dip of the needle sufficiently show: and the facts connected with electro-magnetism lead to the conclusion, that, when a magnetic needle is in its natural position of north and south, there exist electrical currents in planes of right angles to the needle descending on its east side, and ascending on its west side; we must hence suppose that currents of Electricity are constantly circulating within the earth, especially near its surface, from east to west, in planes parallel to the magnetic equator.

(701) The cause of these electrical currents has been thus explained by Ampère. The earth, during its diurnal motion on its axis from west to east, has its surface successively exposed to the solar rays, in an opposite direction, or from east to west. The surface of the earth, therefore, particularly between the tropics, will be heated and cooled in succession, from east to west, and currents of Electricity on thermo-electric principles will, at the same time, be established in the same direction: now, these currents once established, from east to west, will, of course, give occasion to the magnetism of the earth

from north to south. Hence, the magnetic directive power of the earth, in a direction nearly parallel with its axis, is derived from the thermo-electric currents induced in its equatorial regions by the unequal distribution of heat there present, and depending principally on its diurnal motion.

The actual existence of these electrical currents has been fully established *by the experiments of Fox, Reich,* and others, made in mines. It was ascertained, by the former, that by connecting two distant parts in the same vein, with the wires of a galvanometer, that currents of different degrees of intensity run in some cases from east to west, and in others, from west to east. Reich verified this observation in the mines of Saxony, and he found that the direction of the currents depended on the geographical situation of the place, and on the depth of the station below the surface.

CHAPTER XII.

THE THEORY OF THE VOLTAIC PILE.

(702) Is the proximate cause of the voltaic current the contact of the two dissimilar metals, or is it the action of the oxidizable metal on the water of the acid solution? This question has been the subject of much profound discussion. It has already been stated that the first view of the subject was adopted by Volta, who, attributing the Electricity of the pile to the contact of dissimilar metals, regarded the interposed solutions merely as imperfect conductors, admitting the transfer of Electricity when the circuit was completed; and when incomplete, throwing the whole by induction into an *electro-polar* state. This view has been adopted and reasoned on, with their peculiar ingenuity, by the German philosophers; on the other hand, a powerful mass of evidence has been brought against it by Faraday, and the chemical theory has obtained, in this country at least, almost universal assent.

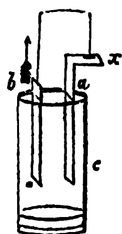
(703) It will be proper, however, to attempt a popular account of the present state of this interesting question. By Davy the electric state of the pile was considered as due partly to the contact of the opposed metals, and partly to the chemical action exerted on them by the liquid. He concluded, to use his own words,* that "chemical and electrical attractions are produced by the same cause; acting, in one case, on *particles*, in the other on *masses* of matter; and that the same property, under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations." By Dr. Wollaston the phenomena were referred solely to chemical action; and he even attributed the Electricity of the common machine to the oxidizement of the amalgam, and found, contrary to the experiments of his great contemporary, that the electrical machine was not active in atmospheres of hydrogen, nitrogen, or carbonic acid. The first suggestion, however, of the chemical origin of voltaic Electricity is to be found in a paper communicated by Fabroni, in 1792, to the Florentine Academy. This philosopher ascribed the convulsions in the limbs of the frog, in the experiments of Galvani and Volta, to a chemical change made by the contact of one of the

* Philosophical Transactions, 1826, p. 389.

metals with the liquid matter on the parts of the animal body; to a decomposition of this liquid; and to the transition of oxygen from a state of combination with it, to combination with the metal. He maintained that the convulsions were chiefly due to the chemical changes, and not to the Electricity incidental to them, which he considered, if operating at all, to do so in a secondary way. Pepys placed a pile in an atmosphere of oxygen, and found that in the course of a night, 200 cubic inches of the gas had been absorbed; while in an atmosphere of azote, it had no action. MM. Biot and Cuvier also observed the quantity of oxygen absorbed, and inferred from their experiments that, "although, strictly speaking, the evolution of Electricity in the pile was produced by oxidation, the share which this had in producing the effects of the instrument bore no comparison with that which was due to the contact of the metals, the extremities of the series being in communication with the ground."

(704) The source of the Electricity of the voltaic pile was made by Faraday the subject of the 8th, 16th, and 17th series of his Experimental Researches. By the arrangement shown in Fig. 247 he succeeded in producing Electricity *quite independent of contact.* A plate of zinc (Fig. 247) was cleaned and bent in the middle to a right angle; a piece of platinum, about three inches long and half an inch wide, *b*, was fastened to a platinum wire, and the latter bent as in the figure. These two pieces of metal were arranged as shown in the sketch; at *x* a piece of folded bibulous paper, moistened in a solution of iodide of potassium, was placed on the zinc, and was pressed upon by the end of the platinum wire; when, under these circumstances, the plates were dipped in the diluted nitric and sulphuric acids, or even in solution of caustic potash, contained in the vessel *c*, there was an immediate effect at *x*, the iodide being decomposed, and iodine appearing at the anode, that is, against the end of the platinum wire. As long as the lower ends of the plates remained in the acid, the electric current proceeded, and the decomposition proceeded at *x*. On removing the end of the wire from place to place on the paper, the effect was evidently very powerful; and on placing a piece of turmeric paper between the white paper and the zinc, both papers being moistened with a solution of iodide of potassium, alkali was evolved at the *cathode* against the zinc, in proportion to the evolution of iodine at the *anode;* the galvanometer also showed the passage of an electrical current; and we have thus a simple circle of the same construction and action as

Fig. 247.

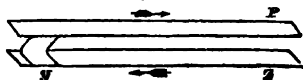


those described in Chapter VII., except in the absence of metallic contact.

(705) It is shown by Faraday that *metallic contact* favours the passage of the electrical current, by diminishing the opposing affinities. When an amalgamated zinc plate is dipped into dilute sulphuric acid, the force of chemical affinity exerted between the metal and the fluid is not sufficiently powerful to cause sensible action at the surfaces of contact, and occasion the decomposition of the water by the oxidation of the metal, though it *is* sufficient to produce such a condition of Electricity as would produce a current if there were a path open for it; and that current would complete the conditions necessary, under the circumstances, for the decomposition of water. Now, when the zinc is *touched* by a piece of platinum, the path required for the Electricity is opened, and it is evident that this must be far more effectual than when the two metals are connected through the medium of an *electrolyte;* because a *contrary and opposing action* to that which is influential in the dilute sulphuric acid is then introduced, or at any rate the affinity of the component parts of the electrolyte has to be overcome, since it cannot conduct *without decomposition*, and this decomposition re-acts upon, and sometimes neutralizes, the forces which tend to produce the current.

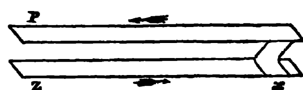
(706) The mutual dependence and state of the chemical affinities of two distant portions of acting fluids, is well shown in the following experiments: Let *P* (Fig. 248) be a plate of platinum, *Z* a plate of amalgamated zinc, and *y* a drop of dilute sulphuric acid; no sensible chemical action takes place till the points *P Z* are connected by some body capable of conducting Electricity: *then* a current passes; and as it circulates through the fluid at *y*, decomposition ensues.

Fig. 248.



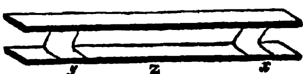
In Fig. 249 a drop of solution of iodide of potassium is substituted, at *x*, for the acid: the same set of effects occurs; but the electric current is in the opposite direction, as shown by the arrows.

Fig. 249.



In Fig. 250 the dilute sulphuric acid and the iodide of potassium are opposed to each other at *y* and *x*: there is no metallic contact between the zinc and platinum; but there is an opposition of forces; the stronger (that brought into play by the acid) overcomes the weaker, and determines the formation and

Fig. 250.



direction of the current; not merely making that current pass through the weaker liquid, but actually *reversing* the tendency which the elements of the latter have in relation to the zinc and platinum if not thus counteracted, and forcing them in a contrary direction to that they are induced to follow, that its own current may have free course.

(707) To decompose a compound by the current from a single pair of plates was considered impossible: by some beautiful experiments, however, Faraday proved that iodide of potassium, protochloride of tin, and chloride of silver, may be decomposed by a single pair, excited with dilute sulphuric acid; and thereby showed the direct opposition and relation of the chemical affinities concerned at the two points of action. Where the sum of the *opposing* affinities was sufficiently beneath the sum of the *acting* affinities, decomposition took place; but in those cases where the opposing affinities preponderated, decomposition was effectually resisted, and the current ceased to pass.

(708) By increasing the *intensity* of the current, without, however, causing *more* Electricity to be evolved, solution of sulphate of soda, muriatic acid, nitrate of silver, fused nitre, and fused iodide and chloride of lead, were decomposed by a single pair. This increase in *intensity* was effected by adding a *little nitric acid* to the dilute sulphuric acid with which the battery was charged; and that this addition caused no increase in the *quantity* of Electricity was rendered evident from the fact, that mere wires of platinum and zinc evolved sufficient Electricity to decompose muriatic acid, which compound would not, however, yield to a large pair of plates excited by dilute sulphuric acid alone.

(709) The source of the Electricity in the voltaic circuit is the chemical action which takes place between the metal and the body with which it combines. As *volta-electro generation* is a case of mere chemical action, so *volta-electro decomposition* is simply a case of the preponderance of one set of chemical affinities more powerful in their nature, over another set which are less powerful; and the forces termed chemical affinity and Electricity are one and the same. It is the union of the zinc with the oxygen of the water, that determines the current in the common voltaic battery; and the quantity of Electricity is dependent on the quantity of zinc oxidized, and in a definite proportion to it. The intensity of the current is in proportion to the intensity of the chemical affinity of the zinc for the oxygen, under the circumstances, and is scarcely (if ever) affected by the use of either strong or weak acid.

(710) Not chemical *combination* alone, but chemical *decomposition*

also, is requisite to generate a current of Electricity: the simple union of oxygen with zinc will not produce Electricity. The oxygen must be in combination, and the compound of which it is an element must be an *electrolyte*. A pair of plates of zinc and platinum may be heated in an atmosphere of oxygen gas sufficiently high to cause rapid oxidation of the zinc, and yet a voltaic circle will not be formed, neither will any current be excited by immersing the plates in liquid chlorine. Strong chemical action and high ignition are known to attend the combination of platinum and tin; nevertheless, no development of Electricity was found by Faraday to attend the union of these metals; for, though a good conductor, and capable of exerting a chemical action on tin, platinum is *not* an electrolyte, was *not* decomposed, and therefore there was no Electricity.

(711) When a fluid amalgam of potassium, containing not more than a hundredth of that metal, was put into pure water, and connected through the galvanometer with a plate of platinum in the same water, an electric current was determined from the amalgam, through the water, to the platinum; so also, when a plate of clean lead and a plate of platinum were put into pure water, there was a current sufficiently intense to decompose iodide of potassium, produced from the lead, through the fluid, to the platinum. The Electricity in both these cases must be referred solely to the oxidation of the metals, as in neither was there either acid or alkali present to combine with, or in any way act on, the body produced.

(712) Although a piece of amalgamated zinc has not, when alone, power enough to take the oxygen and expel the hydrogen from water, it would appear that it has the power so far to act by its attraction for the oxygen of the particles in contact with it, as to place the similar forces already active between these and the other particles of oxygen, and the particles of hydrogen in the water, in a peculiar state of tension or polarity; and probably also, at the same time, to throw those of its own particles which are in contact with the water, into a similar, but *opposed* state. Practically, this state of tension is best relieved by touching the zinc in the dilute acid with a metal having a less attraction for oxygen than the zinc; the force of chemical affinity is then transferred in a most extraordinary manner through the two metals, and it appears impossible to resist the idea, that the voltaic current must be preceded by a *state of tension* in the fluid, and between the fluid and the zinc. Faraday endeavoured to make this state of tension in the electrolytic conductor evident by transmitting a ray of polarized light through it, but he did not succeed, either with solution of sulphate of soda or nitrate of lead.

(713) By a series of beautiful experiments Faraday has shown

that electrolytes can conduct a current of Electricity of an intensity too low to decompose them; and in the case of water, when the current is reduced in intensity below the point required for decomposition, then the degree of conduction is the same, whether sulphuric acid or any other of the many bodies which can effect its transferring power as an electrolyte, are present or not; or, in other words, that the *necessary* electrolytic intensity for water is the same, whether it be pure, or rendered a better conductor by the addition of these substances; and that for currents of less intensity than this, the water, whether pure or acidulated, has equal conducting power. The following remarkable conclusion is also pointed out, viz., that when a voltaic current is produced, having a certain intensity, dependent upon the strength of the chemical affinities by which that current is excited, it can decompose a particular electrolyte without relation to the quantity of Electricity passed; the *intensity* deciding whether the electrolyte shall give way or not; and if this be confirmed, circumstances may be so arranged that the *same* quantity of Electricity may pass in the *same time, in at* the *same surface,* into the *same decomposing body in the same state,* and yet differing in intensity, will *decompose in one case and not in the other:* for, taking a source of too low an intensity to decompose, and ascertaining the quantity passed in a given time, it is easy to take another source, having a sufficient intensity, and reducing the quantity of Electricity from it, by the intervention of bad conductors, to the same proportion as the former current, and then all the conditions will be fulfilled which are required to produce the result desired.

(714) What follows is exceedingly important. From the principles of electrolytic action, it is evident that the *quantity* of Electricity in the current cannot be increased with the *quantity* of metal oxidized and dissolved at *each new place of chemical action:* hence, in the compound voltaic battery, the action of the number of pairs of plates is only to urge forward that quantity of Electricity which is generated by the first pair in the series, and this is effected by the amount of decomposition of water and oxidation of zinc being *equal* in each cell. A little consideration will render this evident; for, if we consider that by the decomposition of a certain quantity of water in the first cell a certain quantity of Electricity (equivalent to that associated with the water decomposed) is evolved, it is clear that, before this Electricity can pass through the second cell, an equal quantity must be decomposed, and this can only be effected by the oxidation of an equal weight of zinc: and so, for each succeeding cell, the electro-chemical equivalent of water must be decomposed in each before the current can pass through it; and this theoretical deduction

Faraday has proved by direct experiment. Each cell, then, gives a fresh impulse to the Electricity generated in the first cell; or, in other words, increases the *intensity* of the current; and though we may not know what *intensity* really is, being ignorant of the real nature of Electricity itself, it is not difficult to imagine that the *degree* of intensity at which a current of Electricity is evolved by a first voltaic element shall be increased when that current is subjected to the action of a second voltaic element, acting in conformity, and possessing equal power, with the first.

(715) It is argued by Poggendorf (who published in his "Annalen," Jan. 1840, a most profound paper on the theory of the voltaic pile) that the electrolytic law is no proof of the chemical origin of the Electricity of the voltaic apparatus, inasmuch as it is the property of *all* currents, voltaic, frictional, magnetic, thermal, and animal, to decompose on their passage through a series of different fluids, equivalent quantities of each. But the greater part of this elaborate memoir is directed against that experiment on which so much stress is laid by the supporters of the chemical theory, in which, as we have seen, two strips, one of zinc and the other of platinum, are separated at their extremities, on the one side by sulphuric acid, and on the other side by a solution of iodide of potassium. An electric current then occurs in a direction which indicates the preponderance of the sulphuric acid circuit over that of the iodide of potassium. Now, in this experiment there is—*first*, the affinity of the oxygen for the zinc; and *second*, the affinity of iodine for the same metal; both endeavour to excite a current, but that of the oxygen being the strongest, sets more Electricity in movement than that of the iodine; the latter is, therefore, overpowered, and a current thus originates in the direction of the affinity of the oxygen, which, at the same time, since the two metals do not touch, is considered as affording a proof of the non-necessity of metallic contact to excite voltaic Electricity.

(716) On this experiment the following remark is made by Poggendorf: "The experiment is so remarkable, and the explanation given has in appearance so much plausibility, that it is not to be wondered at if the supporters of the chemical theory have regarded it as the main prop of their opinion. Upon the defenders of the contact theory, however, it made but little impression, probably from their believing that no regard need be had to an isolated fact speaking apparently in favour of the chemical theory, considering the numerous objections which may be urged against it. In general, they may have contented themselves with this otherwise perfectly correct position, that one metal as soon as it is in contact with two fluids, can no longer be regarded as a single metal; so that in Fara-

day's experiment that end of the zinc bar which touched the sulphuric acid would be positive towards that which was moistened by the solution of iodide of potassium." The German professor then details a vast number of experiments made with two metals and two fluids not in contact, and states the following as the main results: *That the magnitude of the electro-motive force in general is altered, sometimes increased, sometimes diminished, by any substances added to water, be it an electrolyte or not, and, indeed (which should be well observed), increased for one metal combination, and diminished for another, by the same substance, added to the water in the same proportion. Nor has he been able to find that this force stands in direct ratio to the energy of the affinity between the positive metal and the negative constituent of the fluid. It is weak in cases where this energy must be considered as strong, and, on the contrary, strong where but a weak affinity can be admitted. Frequently, indeed, a current originates, and at times a powerful one, where, to judge from the affinity, not the slightest action should be expected.*

(717) As another result of his experiments, Poggendorf submits that the position that those bodies which, brought between the metallic elements of the voltaic pile render it active, are all electrolytes,* must be thus altered, "that the fluids between the metallic plates must, it is true, be electrolytes, *i. e.*, decomposable bodies, since, at least with aqueous fluids and with a certain intensity of current, no conduction can take place without decomposition; but that the electro-motive force which is developed on the contact of these fluids with the metals, is not in any necessary connection with the conductivity or decomposability, and can be increased or diminished by bodies which are *not* electrolytes, *i. e.*, not directly decomposable."

(718) Professor Poggendorf is not satisfied with the *passive* part which the chemical theory assigns to the negative metal in a voltaic combination. He thinks his experiments warrant the conclusion that it is essential to the *generation* of the current. If the negative metal in a circuit has merely to act a passive part, to perform merely the function of *conducting*, then the best conductor should produce the strongest current, or rather, the greatest electro-motive force; and as copper is a better conductor of Electricity than platinum, a copper-zinc circuit ought to be more efficacious than a platinum-zinc circuit, which is contrary to fact.

(719) With respect to the experiment with sulphuric acid and iodide of potassium, the German electrician states that it is only at *first* and *transitorily* that the sulphuric acid has the ascendancy, and

* Faraday's Exp. Researches, 858, 921.

that subsequently, although unquestionably it attacks the zinc more violently than the iodide of potassium, it gives way to the latter salt: a fact he thinks conclusive against the chemical theory. The reason that Faraday obtained different results is to be accounted for from the sulphuric acid not being pure, but mixed with nitric acid, in which case it always maintains a high degree of superiority over iodide of potassium. The addition of the nitric acid, according to Faraday's theory, increases the *intensity* without interfering with the *quantity* of the Electricity produced; but if the intensity of a chemical action is to be measured by the quantity of metal dissolved from a *unity* of surface in the *unity* of time, then if sulphuric and nitric acids be taken of such a degree of concentration that they both dissolve just the same quantity of a like zinc surface in the same time, there is, says the German professor, no reason why the nitric acid should enjoy any single advantage over the sulphuric acid, more particularly as both are non-electrolytes. Nevertheless, as nitric acid does develope a greater degree of electro-motive force than sulphuric acid, the chemical theorists must suppose that the *quality* of the chemical action produces a specific difference in the excited Electricity; but Poggendorf declares that he has convinced himself in the most positive manner, *that the result of the addition of the nitric acid does decidedly not arise from the chemical attack of this acid on the zinc, but solely from an action of it on the platinum.* The acids were separated by animal membrane, a zinc (amalgamated) plate being immersed in the sulphuric, and a platinum in the nitric acid; the two other plates, zinc and platinum, standing in solution of iodide of potassium. The result was, *that the separated acids not only excite an electro-motive force quite as great as the mixed, but have a slight superiority over these:* a fact, in the professor's opinion, perfectly destroying the chemical theory of galvanism. Finally, not only the cases examined in the memoir, but others in previous ones by Fechner and others, are considered as proving in the most evident manner that the energy of the direct chemical attack of the fluid on positive metal does in no way stand in any connection with the intensity of the excited electromotive force; and, on the other hand, is is *not proved* that the local action is ever converted into circulating, or weakened by it.* What has been advanced as such is founded on error. And lastly, it is urged that the decrease of the hydrogen at the zinc, which results on the closing of the circuit, does not happen from a *transfer* of *this* hydrogen to the negative metal, but simply from the oxygen being carried by the current to the zinc, and there combining with the hydrogen.

* Faraday's Exp. Researches, 996.

(720) The theories of voltaic Electricity have been examined with much attention by Professor De la Rive, of Geneva. The following is a brief abstract of an admirable memoir which he published in 1828, entitled, "*Analysis of the circumstances which determine the direction and intensity of the electric current in a voltaic pair.*"

(721) 1st. He strongly contends that, insuring the absence of calorific and mechanical action, no Electricity can be developed in bodies, when they do not undergo chemical action. All the experiments that have hitherto been brought forward in opposition to this are unsatisfactory, owing to the very great difficulty of securing the absence of chemical action in their prosecution. Messrs. Pfaff and Becquerel employed a condenser, of which one of the plates was copper and the other zinc, between which a communication was established by means of an insulated arc of copper: the plates were in vacuo, in hydrogen, or in azote carefully dried; or the copper plate was gilt, and the zinc plate covered with a thin coating of lac varnish. But De la Rive says, it can easily be shown, that in one case sufficient air (atmospheric) is always present to produce slight oxidation of the zinc; and in the other, the coating of varnish is too thin to prevent oxidation, which took place through the pores the alcohol produced by evaporation.

(722) But chemical action may be entirely excluded. Pairs of platinum and rhodium, and pairs of platinum and gold, give no current in very pure nitric acid; nor do pairs of platinum and palladium in dilute sulphuric acid; but a drop of hydrochloric acid in the one, or nitric acid in the other, immediately determines one. The following experiment was made:—

Two plates of perfectly polished steel were immersed in a flask containing solution of potash: one was insulated, and the other metallically fixed by its extremity to a plate of platinum immersed in the same liquid: the two steel plates were fixed in a cork, the upper end of each passing into the air. In three years the immersed surfaces had not lost any degree of polish; yet, according to Volta, the plate connected with the platinum ought to have been oxidated, particularly, since potash is a good conductor of Electricity. The ends outside the cork were both oxidated—the associated plate by far the most so: hence it follows that oxidation must have commenced in order to the existence of an electric current. The current produced by this oxidation decomposes water, and, in consequence, determines a stronger oxidation on the steel plate connected with the platinum; and this oxidation, in its turn, increases the energy of the current, and is thus both cause and effect.

(723) He says sufficient attention has not been paid to the forma-

tion of coatings of *suboxide* on the surfaces of metals, which sometimes take place with great rapidity, and may be seen, by comparing the recently brightened surface of a metal with one that has for some time been exposed to the air. If a bright surface be rubbed with a cork, the metal is always negative; but if the rubbing be deferred for a time, the metal is always positive, even in dry air. This is evidently occasioned by the formation of a coating of suboxide, which is removed by the rubbing substances, the friction afterwards taking place between the metal and its oxide, which causes the former to be positive. Again, if a metal which has been brightened and allowed to remain for some time in dry air, be fixed to the negative pole of a battery, and a plate of platinum to the positive, and both immersed in dilute sulphuric acid, oxygen appears at the positive pole some seconds before the hydrogen shows itself at the negative, which shows that the latter must have been employed in deoxidating the negative metal.

(724) The experiment of Becquerel, of immersing pure oxide of manganese and platinum in pure water, is also unsatisfactory; for the current is not perceptible for more than half an hour, during which time the Electricity due to chemical action (either from the slight deoxidation of the peroxide, or the formation of a hydrate) is accumulating; here the platinum is positive.

"All chemical action disengages Electricity; but the Electricity disengaged is not, in every case, nor under every form, proportional to the vivacity of the chemical action. Two principal circumstances may explain this anomaly: viz., the immediate recomposition in a larger or smaller proportion of the two Electricities, at the points at which they are separated by chemical action; and the particular nature of this action, which, according to the bodies between which it is exerted, gives rise to electric effects more or less intense."

(725) It is necessary here carefully to distinguish the Electricity *perceived* from the Electricity *produced*: the latter must evidently be proportional to the extent of the chemical action; that is, that in a given time it depends upon the number of *chemical atoms* which are combined, and consequently upon all the other circumstances which may have exerted an influence upon the number of these combinations (the extent of the surface exposed to chemical action, the vivacity of that action, &c.). The Electricity perceived, is a portion of the Electricity produced, a portion which depends on the relative conductibility of the bodies entering into the system in which the Electricity is propagated, upon the disposition of the different parts of the system, and upon the nature of the apparatus to be employed in showing the presence of the Electricity, &c., circumstances which

all have an influence on the degree of facility with which the two electric principles follow some certain course, or become again immediately united to the same surface from which, by chemical action, they are separated.

(726) When a capsule of platinum, filled with sulphuric or diluted nitric acid, is placed upon the plate of a condenser, and a plate of zinc held in the fingers is immersed in it, a very feeble charge is given to the plate of the condenser, although the chemical action may have been very lively: the reason is, not that there has not been an enormous disengagement of Electricity—a fact which may be proved by employing this Electricity in producing a current,—but, in this experiment, the negative Electricity developed in the zinc unites with the positive with much greater facility than it can pass through the fingers and the body of the experimenter in order to lose itself in the earth. There will, therefore, be only a very feeble positive tension, often scarcely any; but if the diluted acid is replaced by concentrated sulphuric acid, though the chemical action will be less lively, the electric tension will be much stronger, this acid being a very bad conductor, and the passage of the Electricity from the liquid to the metal immersed in it, being extremely difficult, the two Electricities uniting, on the surface attacked, in much smaller proportions: if, instead of a piece of metal, a piece of wood, rather moist, is immersed in the concentrated sulphuric acid, the *positive tension* acquired by the acid is still stronger. If a capsule, made of an oxidable metal, be employed, and after heating it, a few drops of a liquid capable of attacking it at that high temperature, in ever so small a degree (pure water is sufficient), be poured into it, a quantity of negative Electricity is developed, which is sufficiently strong to be sensible without the assistance of the condenser, and even to give sparks. In this case, the drop of liquid injected into the heated capsule is converted into vapour while it is attacking the metal, and carries off with it the positive Electricity which cannot then combine immediately with the negative Electricity left in the metal; but if even the smallest quantity of liquid remains in the capsule, unvaporized, the immediate recomposition takes place, and only very feeble traces of negative Electricity can be obtained. If the Electricity developed by the action of a gas, or by that exerted by a humid body, such as the hand or a piece of wood, upon the metal with which it is in contact, be often much stronger than the Electricity resulting from the much livelier action of a liquid, the reason is, that in the former case, the *immediate recomposition* of the two electric principles is almost *null*, in consequence of the imperfect conductibility of the exciting bodies, and that the Electricity pro-

duced is almost entirely perceived. There *is*, however, a slight recomposition; for the negative tension of an insulated metal is sensibly augmented by giving a *translatory* motion to the gas which attacks its surface; the consequence of which is, that the positive Electricity accumulated in the gas, being removed with it, cannot unite with the negative left in the metal. The principle of the immediate recomposition of the two Electricities applies also to the production of electric currents in a pair. In very lively chemical actions, the larger proportion of the Electricities developed often undergoes this recomposition; a small part only runs through the whole circuit, especially if it be not a very good conductor, which is the reason that the strongest currents are not always those produced by the most lively chemical actions, and that in a pair, the metal most attacked *is not always the positive one;* that is, the one whence the current commences. However, the latter case occurs only when each of the two metals of the pair are immersed in different liquids. A single example may be adduced: a plate of zinc is immersed in concentrated sulphuric acid, and a plate of copper in nitric acid: the two acids are immediately in contact, and the two metallic plates communicate by means of the wire of a galvanometer. In this pair the zinc is positive, though it is much less attacked than the copper, because the two Electricities developed by the action of the sulphuric acid on the zinc, can be more easily reunited by making the tour of the circuit, than by passing from the sulphuric acid to the zinc, and reciprocally; while, on the contrary, the two Electricities developed by the action of the nitric acid on the copper, reunite immediately with the greatest facility, in consequence of the conductibility of the nitric acid, and the ready passage of the Electricity from that acid to the copper; while to make the circuit, they would be obliged to traverse the concentrated sulphuric acid, which is a very imperfect conductor, and pass from the zinc to the acid—a very difficult passage. Two circumstances prove the exactitude of this explanation: 1. The same result is obtained in the preceding experiment by substituting a plate of zinc similar to that which is immersed in the sulphuric acid for the plate of copper immersed in the nitric acid. 2. If a capsule of platinum be put upon the plate of a condenser, and filled in succession with nitric acid and concentrated sulphuric acid, and a plate of copper or zinc held between the fingers, be immersed in the former liquid, and a plate of zinc in the latter, a much stronger positive Electricity is obtained in the second case than in the first.

(727) In applying these principles to the explanation of the theory of the voltaic pile, De la Rive remarks, that the use of the pile is to

facilitate the passage of the current through imperfect conductors, and *not to increase the quantity of Electricity*; for the utmost that can be effected by a pile composed of a certain number of similar pairs is to compel all the Electricity produced by only *one* of its pairs, to pass through the conducting body which connects its poles. The only means of attaining this object is to separate the two metals of a pair by other pairs, as similar to the first as possible. These intermediate pairs, the number of which should correspond to the more or less imperfect conductibility of the bodies interposed, will each produce as much Electricity as the extreme pairs. But these Electricities do *not pass through the conductor*, they only compel the Electricities of the extreme pairs to pass through it almost in totality.

(728) Let us see how this effect is produced. "We shall take a pile in activity, and suppose that all the pairs of which it is composed are so exactly similar in every respect that the free Electricity on each of them has the same intensity. Let *b* be a pair in the pile taken at hazard, and disposed in such a manner that its *zinc* is immersed in the same liquid as the copper of the pair *a*, which precedes it; and its copper in the same liquid as the zinc of the pair *c*, which follows it. The chemical action of the liquid upon the zinc of the pair *b*, developes in it a certain quantity of Electricity; the portion of this Electricity, which does not undergo immediate recomposition, remains free, and the same for all the pairs, they being similar and symmetrically disposed with relation to each other. According to this, the positive Electricity of *b*, developed by chemical action, in the liquid in which the copper of *a* is immersed, neutralizes the negative Electricity of this latter pair, which is equal to it. In the same manner, the negative Electricity of *b*, which by chemical action is carried to the zinc, and thence to the copper in contact with the zinc, neutralizes the positive Electricity of *c*, which also is perfectly equal to it. There remains, then, an excess of free positive Electricity in the liquid in which the zinc of *a* is immersed, and an excess of free negative Electricity, perfectly equal upon the copper of *c*. But these free Electricities are neutralized by the equal and opposite Electricities of the following pairs, with regard to which we may reason in the same manner as for the pairs *a*, *b*, *c*. Thence there results an excess of free positive Electricity at the extremity of the pile, at the side of *a*; and an exactly equal excess of negative Electricity at the extremity, situated at the side of *b*. Such is found to be the fact, if a communication be established between each of the extremities and an electroscope: and if they be united by a conductor the two excesses of free Electricity are collected together and form the current. The intensity

of this current, as experiment has proved, ought to be perfectly equal to that of the current which is established in the pile itself between all the pairs."

(729) M. de la Rive next proceeds to show how it happens, that though the quantity of free Electricity developed upon each pair of the pile be frequently not *mathematically* the same, yet the current which traverses a conductor, uniting the two extremities, is still *mathematically* equal to that which traverses each of the pairs.

To establish this important result, instead of soldering the zinc and copper of the same pair to each other, an independent conductor must be fixed to each. By means of these two conductors, a metallic communication is established between the two metals of the pair by the intervention of one of the wires of a double galvanometer, the second wire of which serves as conductor to the current of a second pair of the same pile, or to effect a communication between the two poles.

(730) If these two currents are carefully made to pass in contrary directions in each of the wires of the galvanometer, their action on the needle will be always found absolutely null, provided they are mathematically equal. This equality is easily explained. Take the most feeble pair in the pile; let *b* be the pair; the positive Electricity disengaged by *b* cannot neutralize all the negative of *a*; there will remain then, in the copper of *a*, an excess of negative Electricity, which will retain, by neutralizing it, an equal quantity of positive; the result will be, that *a*, though much stronger than *b*, can only set at liberty a quantity of positive Electricity equal to that of *b*. It appears from this analysis, that the current of each pair, and consequently the current of the whole pile, should be equal to the current produced by the *weakest pair*. Now experiment fully proves, that if a feeble pair is introduced into a pile composed of energetic pairs, the immediate result is a considerable diminution in the force of the current of the pile, and consequently of the current of each of the other pairs. But this reduction is never sufficient to render this current equal to that which would be developed by the pair introduced in an insulated state. Indeed, any pair whatever necessarily produces a greater quantity of Electricity when it is in the circuit than when it is isolated. From these valuable remarks we see how necessary it is, in the construction of compound voltaic batteries, to prepare plates as similar as possible, both in size and quality of metal; for of how many pairs soever the arrangement may consist, and how perfect and alike soever all the other pairs may be, the introduction of one smaller or faulty pair will inevitably reduce the power of the battery to that which would result from an equal number of pairs of plates of the size and condition of the feeble pair.

(731) The same indefatigable electrician published also in 1836 another essay, embodying a series of experimental arguments against the contact theory. This memoir was afterwards replied to by Fechner, in a paper published in Poggendorf's Annalen,* entitled "Justification of the Contact Theory." We shall give one or two extracts from each of these memoirs, more, however, with a view of exhibiting specimens of the profundity of thought and skill thrown by both parties into the argument, than with an expectation of enabling any of our readers to form a conclusion respecting these hardly-contested theories.

(732) Amongst other important experiments, quoted by De la Rive, is the following: A piece of potassium or sodium was fixed, in a solid manner, by one of its ends to a platinum forceps, while the other extremity was held by means of a wooden or ivory one. If, after having well brightened it, it is surrounded by very pure oil of naphtha, and the condenser be touched with the end of the platinum forceps, no electrical sign is observable; while, if the naphtha oil is taken off, and none remain adhering to the metal, this is observed to oxidate rapidly by the contact of the air, and the Electricity indicated by the electroscope is of the most lively kind. The condenser is scarcely necessary to render it perceptible. If, sometimes, some indications of Electricity are obtained when the potassium or sodium is on the oil of naphtha, then a small quantity of humidity has been introduced into the liquid, which had remained adhering to the surfaces of the two metals, and which exercises on them a chemical action, which it is easy to recognise. Immersed in azote and in hydrogen, the two metals still give rise to a development of Electricity, proceeding from the action exerted upon them, either by the gas or by the aqueous vapour, from which it is impossible entirely to free them; and in proof of this chemical action, we see their surfaces lose their metallic brightness and become tarnished very much, as would have taken place in the air.

(733) By a variation in the method of performing this experiment, Fechner brings it forward as furnishing an argument *against* the chemical theory. If the potassium be brought into connection with the earth by means of *moist* wood, then powerful action is produced *in* the petroleum, arising, according to the chemical theory, from the chemical action produced through the moisture, and, according to the contact theory, from the increased conducting power of the wood. If the one-half of the bar of wood, which stood in connection with the potassium, was moistened, and the other half air-dried, then no effect was produced on the condenser, provided the dry half of

* Vol. xiii. p. 481.

the wood was held in the hand; and this was even the case if the potassium was moistened with acidulated water during the contact, so that a violent chemical action took place, a proof that the non-conducting power of the dried wood is sufficient to explain the negative result.

A delicate electrometer was constructed to present the smallest possible surface: it consisted solely of a very thin and short brass wire, which, as the axis of a surrounding gum lac cylinder, traversed the perforated bottom of an inverted drinking-glass, and from which, within the glass, was suspended, between the pole plates of a dry pile, a very small gold leaf, 2½ inches long, while the Electricity could be transferred to the prominent end of the brass, without the glass. Into the potassium ball was inserted a thin platinum wire, as short as the convenience of transfer of the Electricity allowed, and the ball itself, for the purpose of increasing its surface, was pressed between two copper plates, which had been soaked in petroleum, as smooth as was possible, without cutting the potassium ball with the platinum wire. Thus, the entire electrometer might have been somewhat about double the size of the surfaces of the potassium. The potassium disc, with the upwards-bent platinum wire proceeding from it, was placed in a small glass, and covered with petroleum to about half an inch high, the platinum wire which projected from the petroleum, and which nowhere touched the glass, was discharged on to the electrometer, the glass being held in the hand. *The divergence to the side which indicates the negative Electricity followed in this case quite as constantly, evidently, and certainly, as if the potassium had been insulated in the air.* It is true, observes Fechner, that when the potassium is brought from the air into the petroleum, the chemical action of the adhering moisture is shown by the gas bubbles which rise from the liquid; but this development of gas soon ceases, and, twenty-four hours after it had *entirely* disappeared, the electrical signs in the petroleum were *of quite the same force* as during the development of gas, and even in the air, so that any objection raised on the grounds of chemical action is valueless, and the experiment is entirely in favour of the *contact* theory.

(734) Some experiments are described by De la Rive, in which two similar plates of zinc are furnished with a brass knob soldered to each, the inner surface of one plate, and both exterior and interior surfaces of the other, being covered with lac varnish. When these plates are made sometimes to stand in the place of the plates of a condenser, and sometimes using one of them and another brass plate, it was shown that when entirely protected from the action of the air by means of a layer of varnish, a plate of zinc does not become

electric in its contact with a brass knob, and, indeed, that it conducts itself as a homogeneous plate of brass; for when the brass knob was touched with the copper element of a heterogeneous plate, the zinc of which was held in the hand, it became charged with negative Electricity, though, according to the contact, theory all kind of action should have been neutralized, from the opposition of two pairs of plates perfectly similar.

(735) These experiments were repeated by Fechner with contrary results. He states, that in order to lay aside the objection which perhaps might be raised respecting the chemical action of the air upon the copper knob, he fixed a platinum wire to it, and then varnished the whole over so as to have the platinum alone exposed. Nevertheless, when the platinum was touched with the finger or with a slip of paper moistened in distilled water, the zinc condensers became quite as well charged with positive Electricity as if it had not been varnished. Becquerel and Peltier arrived at similar results;* and Pfaff, who states that he repeated De la Rive's experiments quite in accordance with his own statement, always observed the same action of the zinc condensers *with* as without varnish.

(736) The following experiment is produced by Fechner as an *experimentum crucis* against the chemical theory. Ten pairs of zinc and copper, in every respect as equal to one another as possible, were arranged into a "couronne des tasses," so that half of the said pairs produced a current opposite in its direction to that which was originated by the other half. The exciting fluid used was common water. Such an arrangement being connected with the galvanometer can, according to either of the two theories, have no effect upon the needle, provided everything in the two systems of cells be equal; muriatic acid was then put into one of the systems, and it was found that in these circumstances the previous equilibrium was in the first instance maintained, but that by degrees the current of the water cells got the ascendancy over the acid system. "According to the contact theory," says Fechner, "the explanation of this experiment is easy." The addition of muriatic acid increases the action only by diminishing the opposition to the conduction present in the circuit, and this diminution is of as great advantage to the Electricity (which is developed by contact in the cells without acid) in its entire circulation throughout the circuit, as to the Electricity of the pairs of plates which are in the very acid fluid. "How the result is to be explained according to the chemical theory, I cannot conceive."

(737) We think, however, that Schœnbein has given a very satis-

* Traité d'Electricité, ii. p. 139.

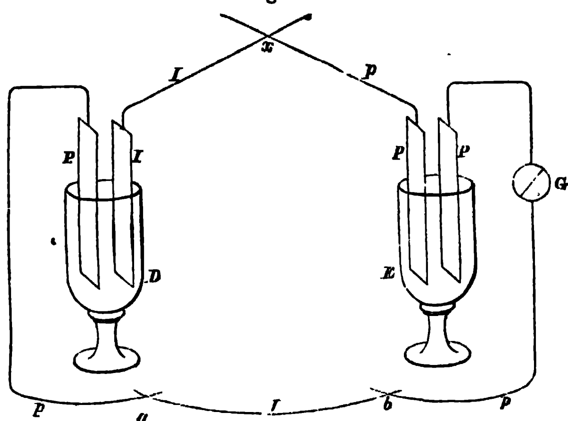
factory explanation of this experiment on the *chemical* principle. From the results of various experiments, it appeared that only in a few instances the chemical difference of the exciting fluids contained in the two systems of cells determines a difference of currents produced by the two sets of pairs, and that the general rule is the production of *current equilibrium*. Now it had been established by De la Rive that the electricities which are set free by chemical action at the two ends of a closed compound circle, unite themselves in two ways: one of which is the pile itself, the other the conductor placed between the poles—the quantities of Electricity recombining within each of the two conducting mediums depending upon the peculiar degree of conducting power in each. If in the case in question we consider the acid cells as originating the current and the water cells merely as the medium placed between the poles, it is evident that by far the larger portion of the Electricity developed must be re-united within the pile, and only a small quantity pass through the water cells and through the galvanometer; but as we know that the water cells also give rise to a current, which, on account of the peculiarity of the arrangement, would be in direction opposite to that excited by the acid cells, it appears from the fact of equilibrium usually taking place, that both currents are generally equal to one another. If ten voltaic pairs be taken, half of them being put into water cells, and the other half into acid ones, and arranged in the usual way, a current is produced much weaker than that which is obtained from five pairs alone placed within the acid fluid. Why (the contact theorist may ask) should this be?—the extent of chemical action in the whole arrangement must be greater than that of only a part!—how then does it happen that the voltaic effect of ten pairs is smaller than that produced by five?* The answer to this question is too obvious to require further consideration.

(738) The celebrated papers of Faraday on the theory of the voltaic pile were read before the Royal Society in February and March, 1840. We shall attempt a brief analysis of these memoirs, as they form the most powerful series of experimental arguments that have hitherto been brought together against the contact theory, and are considered by the great majority of electricians, in this country at least, as quite unanswerable.

In the arrangement shown in Fig. 251, the glasses D E are filled with solution of sulphuret of potassium; P, I, in D, are plates of platinum and iron; and P, P, in E, plates of platinum; G is a galvanometer. Here it will be observed that there are three metallic

* See also, in relation to this subject, the experiments with the water battery.

Fig. 251.



contacts of platinum and iron, viz., at *x*, *a*, and *b*; with certain precautions *no* current passed, though heating either of the junctions at *a*, *b*, or *x*, caused a *thermo-current* deflecting the galvanometer from 30° to 50°; and when the tongue or a wet finger was applied at either of the junctions, a strong current passed: contact of platinum and iron therefore in this case produced nothing. Zinc, gold, silver, potassium, and copper, introduced at *x*, produced no current; so no electromotive force exists between these metals and platinum and iron. Various other combinations of metals were tried with similar negative results. In *green nitrous acid*, iron and platinum produced no current; neither did it in solution of potassium. Now, according to the contact theory, the contact effects between metals and liquids, so far from being balanced, give rise to the phenomena of the pile: it cannot, therefore, be supposed that in the above cases the effects are balanced without straining the point in a most unphilosophical manner. According to the chemical theory, however, the facts admit of very simple explanation: where there is no chemical action there is no current, and a single experiment shows the operator what he is to expect. The contact theory cannot explain why, substituting *zinc* for *iron*, a powerful current should be produced in sulphuret of potassium with platinum; but the chemical theory at once recognizes a chemical action on the zinc, and the same is the case with copper, silver, tin, &c. Many circuits of three substances, all being conductors, were next tried, but without establishing anything like electromotive force.

(739) To account for the current of the voltaic pile, distinct and important cases ought to be brought forward, and not a case where the current is *infinitesimally* small. To account for the phenomena

obtained with sulphuret of potassium, the contact force must be supposed to be balanced in some cases (iron and platinum), and not in others (lead and platinum); in the latter case, the current ceases when a film of sulphuret has been formed by the chemical action, though the circuit be a good conductor. The case, therefore, will stand thus:—

Iron	platinum .	sulphuret of potassium	Electromotive forces balanced.
Lead	platinum. .	sulphuret of potassium	Electromotive forces *not* balanced.
Lead { with a film of sulphuret a good conductor }	platinum .	sulph. potas. . . .	Electromotive forces balanced.

Nothing, therefore, can be predicted by the contact theory regarding results.

(740) Some active circles excited by the sulphuret of potassium are next examined. *Tin* and platinum produced a strong current, tin being *plus;* after a time the needle returned to 0, the tin becoming invested with a non-conducting sulphuret. The current here could not have been produced by the contact force of the sulphuret, because it happens to be a non-conductor.

Lead and platinum produced a strong current which ceased when the lead became invested with sulphuret; nevertheless, though chemical action ceased, and, therefore, no current was called forth, the arrangement conducted a feeble *thermo*-current exceedingly well, the *sulphuret of lead being a conductor:* this was an excellent case in point. Lead and gold, lead and palladium, lead and iron, gave similar results.

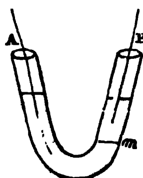
Bismuth with platinum, gold, or palladium, gave active circles, the bismuth being *plus;* in less than half an hour the current ceased though the circuit was still an excellent conductor of thermo-currents. Bismuth with iron, nickel, or lead, produced similar results. Copper, associated with any metal chemically inactive in the solution of sulphuret gave a current, which did not come to a close as in the former cases, and for this reason, the sulphuret of copper does not adhere to the metal, but falls from it in scales, exposing a fresh surface to the action of the sulphuret of potassium. Antimony, platinum, and sulphuret of potassium, produced a powerful and permanent current, but the sulphuret of antimony does not adhere to this metal, which sufficiently explains the phenomenon, showing it to be dependent on chemical action. Sulphuret of antimony is not a conductor. Silver acts like copper; the current is continuous, and the sulphuret of silver separates from the metal. Sulphuret of silver is a non-conductor. Zinc also gives a permanent current, but sulphuret

of zinc is soluble in sulphuret of potassium. Now, sulphuret of zinc is a non-conductor; how then, in this case, can the current be produced by contact? All the phenomena with sulphuret of potassium are decidedly unfavourable to the contact theory: with tin and cadmium, it gives an impermeable non-conducting body; with lead and bismuth, an impermeable conducting body; with antimony and silver, it produces a permeable non-conducting body; with copper, a permeable conducting body; and with zinc, a soluble non-conducting body. The chemical action and its resulting current are perfectly consistent with all these variations; but the phenomena can only be explained on the contact theory by making special assumptions to suit each particular case.

(741) A series of experiments was then made with different metals in solutions unequally heated, and the results were considered as affording striking proofs of the dependence of the current on chemical action, according perfectly with the known influence of heat, and not cognizable by the theory of contact without fresh assumptions being added to those already composing it. The electric current appeared to be determined, not by the amount of chemical action which takes place, but by the intensities of the affinities concerned; and the intensity of currents is exactly proportional to the degree of affinity which reigns between the particles, the combination or separation of which produces the currents.

(742) The effect of dilution is next examined. In Fig. 252, the part below *m* is strong acid, and that above diluted, the wires being platinum, and the fluid nitric acid; drawing the end of the wire B upwards above *m*, or depressing it from above *m* downwards, caused great changes in the galvanometer. The wires, silver, iron, lead, tin, cadmium, and zinc, being compared, it was found that the metal in the weaker acid was *plus* to that in the stronger. The fluids being strong and dilute muriatic acid, and the metals silver, copper, lead, tin, cadmium, and zinc, being compared, the metal in the strongest acid was *plus*, and the current in most cases powerful. The fluids being strong and dilute solution of caustic potash, with iron, copper, lead, tin, cadmium, and zinc, the metal in the strong solution was positive. Cases occurred also in which metals in acids of a certain strength were negative to the same metals in the same acid, either stronger or weaker.

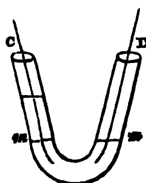
Fig. 252.



Iron and silver being in the tube C D, Fig. 253, whichever metal was in weak acid was positive to the other in the strong acid; it was merely requisite to raise the one and lower the other metal to make

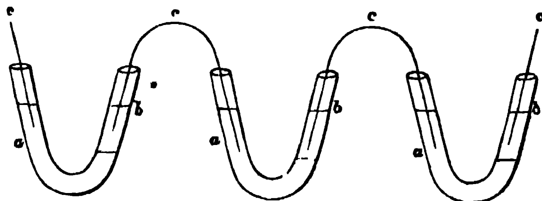
either positive at pleasure. Of the metals, silver, copper, iron, lead, and tin, any one can be made positive or negative to any other, with the exception of silver positive to copper: and such are the wonderful changes that may be brought about by the mere effect of dilution, that the order of these metals may be varied in a hundred different ways by the mere effect of dilution.

Fig. 253.



(743) The same metals in the same acid of the same strength, at the two sides, may be made to change their order thus:—Copper and nickel being put into strong nitric acid, the copper will be positive; in dilute acid the nickel will be positive. Zinc and cadmium, in strong acid: the cadmium will be positive; in dilute acid, the *zinc* strongly positive. An effective battery may be constructed by employing only *one* metal and *one* fluid; thus, if the parts of the tubes at *a*, Fig. 254, contain strong nitric or sulphuric acid, and

Fig. 254.



the parts at *b*, diluted acid of the same kind, then, by connecting these tubes by wires, rods, or plates, (*c*) of one metal only, such as copper, iron, silver, tin, lead, or any of those metals which become positive and negative by difference of dilution in the acid, we have a voltaic arrangement.

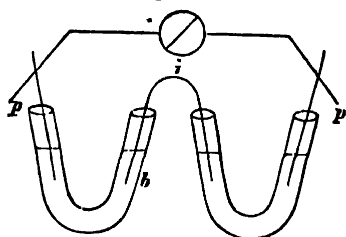
(744) *Where chemical action has been, but diminishes or ceases, the electric current diminishes or ceases also.* If a piece of tin be put into strong nitric acid, it will generally exert no action in consequence of the film of oxide which is on its surface; and if two platinum wires, connected with a galvanometer, be put into the acid, and one of them pressed against the tin, no current will be produced. If now the metal be scratched under the acid, so as to expose a clean surface of metal, *chemical action takes place, and a current is produced;* but this is only for a moment, for oxide of tin is soon formed, chemical action ceases, and the current with it.

(745) *When chemical action changes, the current changes also.* If copper and silver be associated in dilute solution of sulphuret of potassium, the copper will be chemically active and positive, and the

silver will remain clean until of a sudden the copper will cease to act, and the silver will become instantly covered with sulphuret, showing by that, the commencement of chemical action there; and the needle of the galvanometer will jump through 180°.

(746) *Where no chemical action occurs, no current is produced; but a current will occur the moment chemical action commences.* This is well illustrated by the following experiment: In Fig. 255, let both tubes be filled with the same pure, pale, strong nitric acid, and the two platinum wires *p p*, being connected by a galvanometer, and the wire *i*, of iron, no current is produced; now, let a drop of water be put in at *b*, and stir the water and acid together by means of the end of the wire *i*, chemical action commences, nitrous gas is evolved, and the iron wire acquires a positive condition at *b*, producing a powerful current.

Fig. 255.



(747) *When the chemical action which either has, or could have produced a current in one direction, is reversed or undone, the current is reversed or undone also.* It was shown by Volta, in 1802, that crystallized oxide of manganese was highly *negative* to zinc and similar metals, giving, according to his theory, Electricity to the zinc at the point of contact. In 1833, Becquerel examined this subject, and thought the facts favourable to the theory of contact. According, however, to De la Rive, *the peroxide is at the time undergoing chemical change and losing oxygen,*—a change perfectly in accordance with the direction of the current it produces. Peroxide of manganese associated with platinum in green nitrous acid, originates a current, and is *minus* to the platinum; but a chemical action is going on, the peroxide giving up oxygen, and converting the nitrous into nitric acid. Peroxide of lead produces similar phenomena in solution of common salt, and in potash it is *minus* to platinum; but direct experiments show that there is sufficient chemical action to account for the effects.

(748) Faraday concludes his elaborate defence of the chemical theory of galvanism, with the following remarks on the improbable nature of the assumed contact force: "It is assumed that where two dissimilar metals touch, the dissimilar particles act on each other, and induce opposite states; that the particles can discharge these states one to the other, and yet remain unchanged; and that while thus *plus* and *minus*, they can discharge to particles of like matter with themselves, and so produce a current. But if the acting

particles are not changed, it should follow, that the force which causes them to assume a certain state in respect to each other, is unable to make them retain that state, thus denying the equality between cause and effect. If a particle of platinum by contact with a particle of zinc willingly gives off its own Electricity to the zinc, because this, by its presence, tends to make the platinum assume a negative state, why should the particle of platinum take Electricity from any other particle of platinum behind it, since that would only tend to destroy the very state which the zinc had just forced it into? This is quite contrary to common induction; for there a ball, rendered negative, not only will not take Electricity from surrounding bodies, but if we force Electricity into it, it will, as it were, be *spurred back again* wth a power equal to that of the inducing body. Or, if it be supposed that the zinc particle, by its inductive action, tends to make the platinum particle positive, and the latter, being in connexion with the earth by other platinum particles, calls upon them for Electricity, and so acquires a positive state, why should it discharge that state to the zinc—the very substance which, making the platinum assume that condition, ought, of course, to be able to sustain it? Or why should not Electricity go from the platinum *to the zinc*, which is as much in contact with it as its neighbouring platinum particles are? Or if the zinc particle, in contact with the platinum particle, tends to become positive, why does not Electricity flow to it from the zinc particles behind, as well as from the platinum? There is no sufficient, probable, or philosophic cause assigned for the assumed action, or reason given why one or other of the consequent effects above-mentioned should not take place. The contact theory assumes, that a force which is able to overcome powerful resistance, *can arise out of nothing*: that without any change in the acting matter, or the consumption of any generating force, a current can be produced, which shall go on for ever against a constant resistance, or only be stopped as in the voltaic trough, by the ruins which its exertions have heaped upon its own course. The chemical theory, on the other hand, sets out with a power, the existence of which is *pre-proved*, and then follows its variations, rarely assuming anything which is not supported by some corresponding simple chemical fact. The contact theory sets out with an assumption to which it adds others, as the cases require, until at last the contact force, instead of being the firm unchangeable thing at first supposed by Volta, is as variable as chemical force itself. Were it otherwise than it is, and were the contact theory true, then the equality of cause and effect must be denied. Then would perpetual motion also be true; and it would not be difficult, upon the first given case of an electric current

by contact alone, to produce an electro-magnetic arrangement, which, as to its principle, would go on producing mechanical effects for ever."

• (749) It would be difficult to give a satisfactory explanation of the theory of Mr. Grove's gaseous voltaic battery, on the contact hypothesis. "Where," says its ingenious author, "is the contact, if not everywhere? Is it at the points of junction of the liquid, gas, and platinum? If so, it is there that the chemical action takes place; and as contact is always necessary for chemical action, all chemistry may be referred to contact; or, upon the theory of a universal plenum, all natural phenomena may be referred to it. Contact may be necessary; but how can it stand in the relation of a cause, or of a force?" In the opinion of Mr. Grove, the most interesting effect of this extraordinary battery is the fact which it establishes, that gases in combining and acquiring a liquid form, evolve sufficient force to decompose a similar liquid, and cause it to acquire a gaseous form; for it has been proved, that the gases *evolved* at the electrodes are exactly equal to the quantity absorbed in each pair of tubes.

THE END OF PART I.

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LECTURER ON CHEMISTRY AT ST. GEORGE'S HOSPITAL,
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CONTENTS OF PART II.

CHAPTER XIII.

MAGNETISM.

CHAPTER XIV.

MAGNETISM (Continued).

CHAPTER XV.

MAGNETISM (Continued).

CHAPTER XVI.

MAGNETISM (Continued).

CHAPTER XVII.

MAGNETISM (Continued).

CHAPTER XVIII.

ELECTRO-MAGNETISM.

CHAPTER XIX.

MAGNETO-ELECTRICITY.

CHAPTER XX.

THE ELECTRIC TELEGRAPH.

CHAPTER XXI.

DIAMAGNETISM.

CHAPTER XXII.

MAGNETIC HYPOTHESES.

PART II.

MAGNETISM.

CHAPTER XIII.

Historical sketch—Researches of Gilbert, Halley, Graham, Epinus, Coulomb, Humboldt, Hansteen, Barlow, Morichini, Somerville, Dalton, Cavallo, Brewster, Babbage, Herschel, Harris, Faraday.

(750) ALTHOUGH the *attractive* power of the loadstone—(a ferruginous mineral first discovered in the province of Magnesia in Lydia)—appears to have been known among the nations of the west in times of very remote antiquity, and its properties studied even during the Dark Ages, yet its *directive* power, and that of a needle touched or rubbed with it, was known exclusively to the Chinese. More than a thousand years before our era,* at the obscurely known epoch of Codrus, and the return of the Heraclides to the Peloponnesus, these people employed magnetic cars, on which the figure of a man, whose moveable outstretched arm pointed always to the south, guided them on their way across the vast grassy plains of Tartary; and in the third century of our era, at least seven hundred years before the introduction of the compass in the European seas, Chinese vessels navigated the Indian ocean with needles pointing to the south.

(751) A Neapolitan named Flavio Gioia, who lived in the thirteenth century, has been regarded by many as the inventor of the compass. Dr. Gilbert affirms that Paulus Venetus brought the compass from China to Italy in 1260; and Ludi Vestomannus asserts, that about 1500, he saw a pilot in the East Indies, direct his course by a magnetic needle like those now in use. The *variation* of the needle was discovered two hundred years before the time of Columbus; but the *variation of the variation*, that is, the fact that the variation was not a constant quantity, but varied in different latitudes, was first noticed by the discoverer of America, as appears from the following extract from Irving's "Life and Voyages of Columbus," (vol. i, p. 201): "On

* Humboldt's "Cosmos."

the 13th of September, 1492, he perceived about night-fall that the needle, instead of pointing to the north-star, varied about ½ a point, or between 5 and 6°, to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, but to some fixed and invisible point. The variation was not caused by any failing in the compass, but by the movement of the North star itself, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole. The high opinion that the pilots entertained of Columbus, as a profound astronomer, gave weight to his theory, and their alarm subsided."

(752) That ferruginous substances always possess a greater or less degree of Magnetism, has long been known. One Julius Cæsar, a surgeon of Rimini, is said to have first observed the conversion of iron into a magnet. In 1590, he noticed this effect on a bar of iron, which had supported a piece of brick work, on the top of a tower of the church of St. Augustin. The very same fact was observed about 1630, by Gassendi, on the cross of the church of St. John, at Aix, which had fallen down in consequence of having been struck with lightning. He found the foot of it wasted with rust, and possessing all the properties of a loadstone.

(753) In the year 1600, Dr. Gilbert, of Colchester, published a work, entitled "Physiologia Nova, seu Tractatus de Magneti et Corporibus Magneticis," which contains almost everything concerning Magnetism, which was known during the two following centuries. He regarded the earth as acting on a magnetized bar, and upon iron, like a magnet, the directive power of the needle being produced by the action of Magnetism of a contrary kind to that which exists at the extremity of the needle directed towards the pole of the globe. He gave the name of *pole* to the extremities of the needle, which pointed towards the poles of the earth, conformably to his views of terrestial Magnetism; calling the extremity that pointed towards the

north, the south pole of the needle, and that which pointed to the south, the north pole.

(754) Newton, Huygens, and Hooke, with some of the other philosophers who flourished about the end of the seventeenth century, were occupied to a certain extent with the subject of Magnetism. Some of their observations and discoveries are referred to in a manuscript volume of notes and commentaries, written by David Gregory, in 1693, in a copy of Newton's "Principia," and used by Newton in improving his second edition. Newton had supposed that the law of magnetic action approaches to the inverse triplicate ratio of the distance; but Gregory did not adopt this opinion, and invalidates the arguments that were used in its support.

(755) In 1683 Dr. Edmund Halley published his theory of Magnetism. He regarded the earth's Magnetism as caused by four poles of attraction, two of them near each pole of the earth; and he supposes, "that in those parts of the world that lie nearly adjacent to any one of these magnetic poles, the needle is governed thereby, the nearest pole being always predominant over that more remote." He supposes that the magnetic pole, which was, in his time, nearest Britain, was situated near the meridian of the Land's End, and not above 7° from the north pole; the other north magnetic pole being in the meridian of California, and about 15° from the north pole of the earth. He placed one of the two south poles about 16° from the south pole of the globe, and 95° west from London; and the other, or the most powerful of the four, about 20° from the south pole, and 120° east of London.

(756) In order to account for the change in the variation, Dr. Halley, some years afterwards, added to these reasonable suppositions the very extraordinary one, that our globe was a hollow shell, and that within it a solid globe revolved, in nearly the same time as the outer one, and about the same centre of gravity, and with a fluid medium between them. To this inner globe he assigned two magnetic poles, and to the outer one, other two: and he conceived the change in the variation of the needle to be caused by a want of coincidence in the times of rotation of the inner globe and the external shell. "Now supposing," says he, "such an external sphere, having such a motion, we may solve the two great difficulties in every former hypothesis: for, if this exterior shell of the earth be a magnet, having its poles at a distance from the poles of diurnal rotation, and if the internal nucleus be likewise a magnet, having its poles in two other places, distant also from its axis, and these latter, by a gradual and slow motion, change their places in respect of the external, we may then give a reasonable account of the four magnetic poles, as also of the

changes of the needle's variation." From some reasons, which Dr. Halley then states, he concludes "that the two poles of the external globe are fixed in the earth; and that if the needle were wholly governed by them, the variation would be always the same, with some little irregularities; but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive and directive power of each pole, and consequently there must be a period of revolution of this internal ball, after which the variation will return as before."

(757) Mr. Graham, a celebrated mathematical instrument-maker, in London, discovered in 1722, the daily variation of the needle. While the needle was advancing by a gradual motion to the westward, Mr. Graham found that its north extremity moved westward during the early part of the day, and returned again in the evening to the eastward, to the same position which it occupied in the morning, remaining nearly stationary during the night. Mr. Graham at first, ascribed these changes to defects in the form of his needles; but, by numerous and careful observations, repeated under every variation of the weather, and of the heat and pressure of the atmosphere, he concluded that the daily variation was a regular phenomenon of which he could not find the cause. It was generally a maximum, between 10 o'clock A.M., and 4 o'clock P.M.; and a minimum, between 6 and 7 o'clock P.M. Between the 6th of February, and the 12th of May, 1722, he made a thousand observations in the same place, from which he found that the greatest westerly variation was 14° 45′, and the least, 13° 50′; but in general, it varied between 14° 35′ and 14°, giving 35′ for the amount of the daily variation.

(758) Various speculations respecting the cause of the phenomena of Magnetism, had been hazarded by different authors: but it was reserved for M. Epinus to devise a rational hypothesis, which embraced and explained almost all the phenomena which had been observed by previous authors. This hypothesis, which he has explained at great length in his "Tentamen Theoriæ Electricitatis et Magnetismi," published in 1759, may be stated in the following manner:—

i.—In all magnetic bodies there exists a substance which may be called the magnetic fluid, whose particles repel each other with a force inversely as the distance.

ii.—The particles of this fluid attract the particles of iron, and are attracted by them in return, with a similar force.

iii.—The particles of iron repel each other, according to the same law.

iv.—The magnetic fluid moves through the pores of iron and soft steel with very little obstruction; but its motion is more and more obstructed as the steel increases in hardness or temper, and it moves with the greatest difficulty in hard-tempered steel and the ores of iron.

(759) The method of making artificial magnets, which was practised by the philosophers of the seventeenth century, was a very simple, but a very inefficacious one. It consisted in merely rubbing the steel bar to be magnetized upon one of the poles of a natural or artificial magnet, in a plane at right angles to the line joining the poles of the magnet. Towards the middle of the eighteenth century, however, the art of making artificial magnets had excited general attention; and it is to Dr. Gowin Knight, an English physician, that we are indebted for the discovery of a method of making powerful magnets. This method he kept secret from the public, but it was afterwards published by Dr. Wilson. Duhamel, Canton, Michell, Antheaume, Savery, Epinus, Robison, Coulomb, Biot, Scoresby, and others, made various improvements on this art; for a detailed account of their numerous experiments, the reader is referred to the article on Magnetism, drawn up by Sir David Brewster, for the seventh edition of the *Encyclopædia Britannica.*

(760) One of the ablest cultivators of the science of Magnetism was the celebrated Coulomb, who, by the application of the principle of torsion, first used by Michell, determined the correct law of magnetic attraction and repulsion His first object was to determine the law according to which Magnetism is distributed to a magnetic bar. It was of course well known, that the Magnetism in the middle of a bar was imperceptible, and that it increased according to a regular law, and with great rapidity, towards each of the poles. By suspending a small proof needle, with a silk fibre, and causing it to oscillate horizontally opposite different points of a magnetic bar placed vertically, Coulomb computed the part of the effect that was due to terrestrial Magnetism, and the part that was due to the action of the bar; and in this way he showed the extreme rapidity with which Magnetism is increased towards the poles.

(761) In examining the distribution of Electricity in a circular plane, Coulomb found that the thickness of the electric stratum was almost constant from the centre, to within a very small distance of the circumference, when it increased all on a sudden with great rapidity (as has been shown in a previous Chapter.) He conceived that a similar distribution of Magnetism took place in the transverse section of a magnetic bar; and, by a series of nice experiments with

the torsion balance (56) he found this to be the case, and established the important fact that the magnetic power resides on the *surface* of iron bodies, and is entirely independent of their mass.

(762) The effect of temperature on magnets was another subject to which Coulomb directed his powerful mind; but he did not live to give an account of his experiments, which were published after his death by his friend M. Biot. Coulomb found that the Magnetism of a bar, magnetized to saturation, diminished greatly, by raising its temperature from 12° of Reaumur to 680°, and that when a magnetic bar was tempered at 780°, 860°, and 950° of Reaumur, the development of its Magnetism was gradually increased, being more than double at 900° of what it was at 780°. He found also that the directive force of the bar reached its maximum when it was tempered at a bright cherry red heat at 900°, and that at a higher temperature the force diminished.

(763) Coulomb made many valuable experiments on the best methods of making artificial magnets, and he subjected all the various processes that had previously been employed to the test of accurate measurement. His experiments on the best forms of magnetic needles are equally valuable; but the most interesting of his researches, and the last to which he devoted his great talents, were those which relate to the action of magnets upon all natural bodies. Hitherto iron, steel, nickel, and cobalt, had been regarded as the only magnetic bodies; but in the year 1802, Coulomb announced to the Institute of France, that all bodies whatever are subject to the magnetic influence, even to such a degree as to be capable of accurate measurement. In order to determine if the phenomena were owing to particles of iron disseminated through the bodies which he subjected to experiment, he tried a needle of silver, purified by cupellation, and another needle of silver alloyed with $\frac{1}{320}$th part of iron; and he found that the action of a magnet on the former was 415 times less than upon the latter. Hence, as he had previously shown, that the forces exerted by magnets on needles are proportional to the absolute quantities of iron which they contain, there will be 415 times less iron in the pure than in the impure silver; and since the latter contained $\frac{1}{320}$th part of its weight of iron the first will contain $\frac{1}{415}$th part of $\frac{1}{320}$th, or $\frac{1}{132800}$th, or it will contain 132,799 parts of pure silver, and one of iron—a quantity of alloy beyond the reach of chemical detection.

(764) Amongst the scientific travellers who have contributed to our knowledge of terrestrial Magnetism, Baron Alexander Humboldt was one of the most distinguished. Himself a careful and scientific observer, and possessed of accurate instruments and exact

methods of research, he made numerous observations on the dip and variation of the needle in various parts of the earth, and particularly near the magnetic equator; and by means of these valuable data, M. Biot was enabled to throw much light on the subject of terrestrial Magnetism, and to deduce a formula which represented the observations with extraordinary accuracy. Professor Krafft, of St. Petersburg, undertook the same inquiry in the year 1809, and after comparing the same observations which were used by Biot with the respective situations of the places where they were obtained, he arrived at the following simple law: "If we suppose a circle circumscribed about the earth having the two extremities of the magnetic axis for its poles, and if we consider this circle as a magnetic equator, the tangent of the dip of the needle in any magnetic latitude will be equal to double the tangent of this latitude;" and to this simple law, Biot, upon re-examining his former formula, found that it was reducible.

(765) An able work on the Magnetism of the earth was published in 1817, by Professor Hansteen of Christiana; the result of his researches was favourable to that part of Halley's theory, which assumes the existence of four poles and two magnetic axes. He also deduced the law of magnetic action, and showed that "the attractive or repulsive force with which two magnetic particles affect each other, is always directly as their intensities, and inversely as the squares of their mutual distances." And he likewise demonstrated that "the distance from the middle of a magnet being the same, the force opposite the poles, or in the direction of the axis, is double the force in the magnetic equator. Hansteen collected all the observations of value that had been made on the variation of the needle, and from these he proved that there were *four points* of convergence among the lines of variation, *viz.*, a weaker and a stronger point in the vicinity of each pole of the globe. The strongest poles, N. S., lie almost diametrically opposite to each other, and the same is true of the weaker poles, n., s. These four poles he found to have a regular motion obliquely. The two northern ones, N, n, from west to east, and the two southern ones, S, s, from east to west. The following he found to be their periods of revolution, and their positions in 1830:—

	Lat.	Long. from Greenwich.	Time of revolution round each pole of the globe.
Pole N.	69° 30′ N.	87° 19′ N.	1,740 years.
Pole S.	68° 44′ S.	131° 47′ E.	4,609 „
Pole n.	85° 6′ N.	144° 17′ E.	860 „
Pole s.	78° 29′ S.	137° 45′ W.	1,304 „

And on comparing these results with the magnetical observations made by Captain Parry in the Arctic regions in 1819, he found them to differ so little as to give them a high degree of probability. Hansteen showed that the changes in the variation and dip of the needle in both hemispheres, may be well explained by the motion of the four magnetic poles. The same enterprising philosopher, with a view to the determination of the intensity of the earth's Magnetism at different parts of its surface, caused observations on the oscillation of the *same* needle to be made in every part of Europe, and undertook himself a journey to Siberia for the same purpose. From these observations, he deduced the following law, according to which the magnetic intensity varies with the dip of the needle.

Magnetic dip.	Magnetic intensity.
0	1·0°
24	1·1
45	1·2
64	1·3
73	1·4
76⅔	1·5
81	1·6
86	1·7

Hansteen was the first to determine the diurnal variation of the needle. He found that the *minimum* intensity took place between 10 and 11 A.M., and the *maximum* between 4 and 5 P.M.

(766) In an aërostatic voyage made by Gay Lussac and Biot, in 1804, at the height of nearly 13,000 feet, they were unable to detect any change in the intensity of terrestrial Magnetism. Saussure, however, had found that the intensity was considerably less on the Col du Géant than at Chamouni and Geneva; the difference in the levels of these places being in the one case, 10,000, and in the other 7,800 feet; but his observations contradict his conclusions. M. Kupffer has more recently obtained a similar result, by observations on Mount Elbrouz; having found a decrease in intensity in rising 4,500 feet above his first station; and he explains the result obtained by MM. Gay Lussac and Biot, by supposing that an increase of intensity was produced by a diminution of temperature. Mr. Henwood, on the other hand, has made observations at the surface of Dolcoath mine; at 1,320 feet beneath its surface; and on a hill, at 710 feet above the level of the sea; without being able to detect any difference in the intensity. To the late Captain Foster we are indebted for many valuable observations on the magnetic intensity, made at Spitzbergen and elsewhere. From these he concluded that

the diurnal change in the horizontal intensity is principally, if not wholly, owing to a small change in the amount of the *dip*. The maximum took place at about 3h. 30min. A.M., and the minimum at 2h. 47min. P.M.; its greatest change amounting to $\frac{1}{83}$rd of its mean value. Captain Foster is of opinion, that these changes have the sun for their primary agent, and that his action is such as to produce a constant inflection of the pole towards the sun during the twenty-four hours; an idea which had been previously stated by Mr. Christie.

(767) About the year 1818, Professor Barlow, of Woolwich, turned his attention to the subject of Magnetism, with a view principally of calculating the effect of ship's guns on the compass. In trying the effect of different iron balls, he was led to the curious facts—that there exists round every mass of iron, a great circle inclined to the horizon, at an angle equal to the complement of the dip of the needle; —that the plane of this circle is a plane of no attraction upon a needle whose centre is in that plane;—that if we regard this circle as the magnetic equator, the tangent of deviation of the needle from its north or south pole will be proportional to the rectangle of the sine of the double latitude and cosine of the longitude;—that when the distance of the needle is variable, the tangent of deviation will be reciprocally proportional to the cube of the distance, and that all things else being the same, the tangent of deviation will be proportional to the cubes of the diameters of the balls, or shells, whatever be their masses, provided their thickness exceeds a certain quantity. Mr. Barlow was, from these discoveries, enabled to invent a most ingenious method of correcting the error of the compass arising from the attraction of all the iron on board ships. This source of error had been noticed by Mr. Wales, Mr. Downie in 1794, and by Captain Flinders; but it is to Mr. Bain that we owe the distinct establishment and explanation of this source of error. As a hollow shell of iron, about 4 pounds in weight, acts as powerfully at the same distance as a solid iron ball of 200 pounds' weight, Mr. Barlow happily conceived that a plate of 5 or 6 pounds' weight might be made to represent and counteract the amount of the attraction of all the iron on board a vessel; and, therefore, leave the needle as free to obey the action of terrestrial Magnetism as if there was no iron in the ship at all. After this ingenious contrivance had been submitted to the Admiralty, it was tried in every part of the world; and even in the regions which surround the magnetic pole, where the compass becomes useless, it never failed to indicate the true magnetic direction, when the connecting plate was properly applied. "Such an

invention as this," says Captain Parry, "so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial." For this beautiful invention, the Board of Longitude conferred upon Mr. Barlow the highest reward of five hundred pounds; and the Emperor of Russia, who was never inattentive to the interests of science, sent him a fine gold watch and a rich dress chain for the same contrivance.

(768) The late Dr. Morichini, an eminent physician at Rome, first announced it as an experimental fact, that an unmagnetized needle could be rendered magnetic by the action of the violet rays of the sun. His experiments were successfully repeated by Dr. Carpi, at Rome, and the Marquis Ridolfi, at Florence; but M. D'Hombre Firmas, at Alais, in France, Professor Configliachi, of Pavia, M. Bérard, of Montpelier, failed in obtaining decided magnetic effects from the violet rays. In 1814, Dr. Morichini exhibited the actual experiment to Sir Humphry Davy, and in 1817, Dr. Carpi showed it to Professor Playfair. A few months after Sir Humphry witnessed the experiment, Sir David Brewster met him at Geneva, and learned from him the fact, that he had paid the most diligent attention to one of Morichini's experiments, and that he saw an unmagnetized needle rendered magnetic by violet light. The following account of the experiment made by Dr. Carpi, was given to Sir David, by Professor Playfair: "The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found, upon trial, to possess neither polarity, nor any power of attracting iron filings. It was fixed horizontally upon a support, by means of wax, and in such a direction, as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre towards one of the extremities, care being taken never to go back in the same direction, and never to touch the other half of the needle. At the end of half-an-hour after the needle had been exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction; but after continuing the operation 25 minutes longer, when it was taken off and placed on its pivot, it traversed with great

alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned to the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays, repelled the north pole of a compass needle. This effect was so distinctly marked, as to leave no doubt in the minds of any who were present, that the needle had received its Magnetism from the action of the violet rays." In this state of the subject, Mrs. Somerville made some simple and well conducted experiments, which seemed to set the question at rest, from the distinct and decided character of the results. A sewing needle, an inch long, and devoid of Magnetism, had one-half of it covered with paper, and the other exposed to the violet rays of the spectrum, 5 feet distant from the prism. In two hours it acquired Magnetism, the exposed end exhibiting north polarity. The *indigo* rays produced an equal effect, and the *blue* and the *green* the same in a less degree. The yellow, orange, and red rays had no effect even after 3 days' exposure to their action. Pieces of blue watch-spring received a higher Magnetism. When the sun's light fell upon the exposed end through blue-coloured glasses, or through *blue* or *green* riband, the same magnetic effects were produced. The experiments of Mr. Christie, an account of which was read to the Royal Society, a short time before Mrs. Somerville's, confirmed her results to a certain degree, by a different mode of observation. The general opinion seems, however, now to be, that light does not exercise any decided effect in producing Magnetism. The experiments of M.M. P. Ries and Moser were made with needles both polished and oxidated, and also with wires half-polished, and polarized as well as common light was made to fall on them in a concentrated state, but no decided effect upon their number of oscillations could be observed; and they state that they think themselves justly entitled *to reject totally a discovery which for seventeen years has at different times disturbed science.*

(769) On 24th February, 1840, the following account of some experiments on this subject was laid before the Royal Irish Academy by Mr. G. J. Knox and the Rev. T. Knox: "Having procured several hundred needles, of different lengths and thicknesses, and having ascertained that they were perfectly free from Magnetism, we enveloped them in white paper, leaving one of their extreme ends uncovered. Taking advantage of a favourable day for trying experiments upon the chemical ray (known by the few seconds required to blacken chloride of silver), we placed the needles at right angles to the magnetic meridian, and exposed them for 2 hours, from 11 till 1 o'clock, to the

differently refrangible rays of the sun, under coloured glasses. Those beneath the red, orange, and yellow, showed no trace of Magnetism, while those beneath the blue, green, and violet, exhibited, the two first feeble, but the last strong traces of Magnetism.

"To determine how far the oxidating power of the violet ray is concerned in the phenomenon, we exposed to the different coloured light, needles whose extremities had been previously dipped in nitric acid, and found that they became magnetic (the exposed end having been made a north pole) in much shorter time than the others, and that this effect was produced in a slight degree, under the red (when exposed a sufficient length of time), strongly under white glass, and so strong under violet glass, that the effect took place even when the needles were placed in such a position along the magnetic meridian, as would tend to produce, by the earth's influence, a south pole in the exposed extremity.

"Conceiving that the inactive state produced in iron (as observed by Schoenbein, 292 *et seq.*) when plunged into nitric acid, sp. gr. 9·36, or being made the positive pole of a battery, or by any other means, might throw some light upon the nature of the change produced, experiments were instituted to this effect, which showed that no trace of Magnetism could be thereby produced."—(See some curious experiments on the magnetic influence of the *lunar spectrum* in 20th vol. of *Phil. Mag.*)

(770) A valuable series of observations on the influence of the aurora borealis on the Magnetic needle, was made by Dr. Dalton at Kendall and Keswick, during seven years, from May, 1786, to May, 1793, and has been published in his Meteorological Observations and Essays, which appeared in 1793. During these observations he noticed the effect produced on the magnetic needle, and he was thus led to study the phenomena of the aurora, and to establish, beyond a doubt, the relation of all its phenomena to the magnetic poles and equator. In some cases, however, Dr. Dalton did not observe any perceptible disturbance of the needle.

(771) Professor Hansteen, who occupied himself extensively with the subject of magnetism, observes, that large extraordinary movements of the needle, in which it traverses frequently, with a shivering motion, an arc of several degrees on both sides of its usual position, are seldom, perhaps never exhibited, unless when the aurora borealis is visible, and that this disturbance of the needle seems to operate at the same time in places the most widely separate.

(772) From the extensive series of accurate observations, made by M. Arago, at Paris, since 1818, the needle was almost invariably

found to be affected by auroræ that were seen in Scotland; and so striking was the connexion between the two classes of facts, that the existence of the aurora could be inferred from the derangements of the needle. M. Arago has likewise discovered, that early in the morning, often 10 or 12 hours before the aurora is developed in a very distant place, its appearance is announced by a particular form of the curve, which exhibits the diurnal variation of the needle, that is, by the value of the morning and evening maxima of elongation.

(773) During the journey of Captain Back to the polar regions, in 1833, 1834, and 1835, he found that the needle was generally affected by the aurora; and on one occasion the deviation which it produced was 8°; he repeatedly observed that when the aurora was concentrated in individual beams, the needle was powerfully affected; but that it generally returned to its mean position, when the aurora became generally diffused. On several occasions, the needle was restless, and exhibited the vibrating action produced by the aurora, when this motion was not visible; and Captain Back states that he could not account for this, except by supposing the invisible presence of the aurora in full day.

(774) The only metals which were supposed to have a distinct and decided power, and were, therefore, called magnetic metals, are iron, cobalt, and nickel. A needle of the latter metal carefully purified by M. Thenard, was found by Biot to have a magnetic directive power ⅓ that of a similar-sized needle of steel. Mr. David Lyon has endeavoured to show that these metals resemble one another, not only in their principal qualities, but in the numerical values of their qualities; and, he adds, that whilst these three magnetic substances have the values above referred to, near each other, there are no other substances in which the same values come very near, or fall within those of the three magnetic substances. The values to which Mr. Lyon alludes are the following:—

	Specific gravity.	Atomic weight.	Atoms contained in a given space.
Nickel	8·27	739·51	1118
Iron	7·21	678·43	1062
Cobalt	7·8	738	1057

(775) M. Pouillet, on the other hand, thought that there were five simple magnetic bodies, viz., iron, manganese, nickel, cobalt, and chrome; and in consequence of having observed some remarkable analogies, between the distance of the atoms of bodies, and their magnetic properties, he was led to suppose that the magnetic limit of different bodies ought to be found at very different temperatures. "I have, indeed," says he, "demonstrated by experiment, first, that

cobalt never ceases to be magnetic, or rather that its magnetic limit is at a temperature higher than the brightest white heat; second, that chrome has its magnetic limit a little below the temperature of dark blood-red heat; third, that nickel has its magnetic limit about 350° centigrade, nearly at the melting point of zinc; and fourth, that manganese has its magnetic limit at the temperature of from 20° to 25° below zero. Experiments on these five magnetic bodies seem to prove, first, that heat acts upon Magnetism only, in consequence of the greater or less distance which it occasions between the atoms of bodies; and second, that all bodies would become magnetic if we could by any action whatever, make their atoms approach within a suitable distance." It was afterwards shown by Faraday that to Pouillet's list of magnetic metals must be added platinum, palladium, osmium, titanium, and cerium; he has found, moreover, that not only the pure metals, but solutions of their salts are acted on by a powerful electro-magnet in a manner similar to iron.

(776) A series of careful experiments was made by Cavallo on the magnetism of *brass* when hammered. He found that this compound, whether old or new, was made magnetic, when placed between two pieces of card, and hammered, either on an anvil by a hammer, or between two flints. He observes: "It appears that the property of becoming magnetic in brass, by hammering, is rather owing to some peculiar configuration of its parts than to any admixture of iron; which is confirmed still further, by observing, that Dutch plate brass (which is made, not by melting the copper, but by keeping it at a strong degree of heat, whilst surrounded by *lapis calaminaris*,) also possesses that property; at least, such was the case with all the pieces I tried. From this it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c., the brass should either be left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering, which sort, however, does not occur very frequently."

(777) These suggestions of M. Cavallo were not attended to as their importance deserved, and there is no doubt that considerable errors have arisen from their neglect. Many examples have indeed occurred in which the errors were detected; and it is now the invariable practice of well informed instrument makers, to reject hammered brass bowls for compasses, and to use those which are cast and turned for the purpose.

(778) The existence of magnetism in brass, while there was not the least trace of it either in the copper or zinc of which it is composed, led philosophers to investigate the effects produced by the

union of different metals, or by their combination with other substances. Iron itself is a simple chemical body. Steel is a combination of iron and carbon. The loadstone is a combination of iron and oxygen; and as no Magnetism is found either in carbon or in oxygen, we are naturally led to believe, as M. Pouillet has remarked, that the magnetic fluid resides in the substance of the iron, and that it is carried with the atoms of that metal into all the chemical combinations which they form; we may, therefore, expect to find magnetic properties in all ferruginous bodies, whether the iron be an accidental or a necessary ingredient; and indeed cast-iron, plumbago, and the oxides and sulphurets of iron, exert a sensible action on the needle.

(779) On the other hand, Dr. Matthew Young found that the smallest admixture of antimony was capable of destroying the polarity of iron; and M. Seebeck states, that an alloy of one part of iron and four parts of antimony was so completely destitute of magnetic action, that even when put into rotation, it exerted no action on the magnetic needle. The magnetic qualities of nickel (which stands next to iron in magnetic susceptibility, and which is usually found to possess considerable power), are also destroyed by a mixture with it of other metals. Chevenix found that a very small portion of arsenic deprived a mass of nickel, that had previously exhibited a strong magnetic power, of the whole of its Magnetism; and Dr. Seebeck found that an alloy of two parts of copper with one of nickel was entirely devoid of Magnetism, and on this account he recommends it as well suited for the manufacture of compass boxes. On the other hand, Mr. Hatchett ascertained, that when a large proportion of carbon, or sulphur, or phosphorus, was combined with iron, the iron was enabled fully to receive and retain its magnetic properties; but he, at the same time found, that there was a limit beyond which an excess of any of these three substances rendered the compound wholly incapable of receiving Magnetism.

(780) Animal and vegetable substances, after combustion, are said to be attracted by the magnet. The flesh, and particularly the blood, is acted on more powerfully than other parts, and bone less powerfully. Burned vegetables have the same property, and also soot and atmospheric dust; and M. Cavallo has maintained that brisk chemical effervescences acted upon the magnetic needle.

(781) In 1802, the supposition of universal Magnetism was put to the test of rigorous experiment by Coulomb. He employed a glass receiver, from the top of which was suspended, by a silk fibre, the needle of the substance to be examined, about 1 inch long, and $\frac{1}{30}$th thick. The receiver was then placed so as to enclose the opposite poles of two powerful bar magnets, each formed of four bars

of steel tempered to a white heat, and the number of oscillations of the needle between these poles was noted. It was found that *all substances whatever, when formed into small needles, turned themselves in the direction of the poles of the magnets, and after a few oscillations, finally settled in that position.* When these bodies were moved a very little way out of their position of equilibrium, they immediately began to oscillate round it, the oscillations being always performed more rapidly in the presence of the magnets than when they were removed out of their influence. Gold, silver, brass, wood, and all other substances, whether organic or inorganic, thus obeyed the power of magnets. Hence it was concluded, either that all bodies are susceptible of Magnetism, or that they contain minute quantities of iron, or other magnetic metals, which give them their susceptibility. Various other methods have been employed in developing Magnetism in all bodies whatever, since the time of Coulomb; but we must refer for an account of them to the excellent treatise on Magnetism drawn up for the *Encyclopædia Britannica* by Sir D. Brewster. The interesting question of the universal prevalence of Magnetism subsequently derived new interest from the beautiful discovery of M. Arago. This distinguished philosopher conceived the idea of studying the oscillations of a magnetic needle when placed above or near any body whatever. Having suspended a magnetic needle above metal, or even water, and caused it to deviate a certain number of degrees from its position, it began, when left to itself, to oscillate in arcs of less and less amplitude, as if it had been placed in a resisting medium; and what was peculiarly curious in these experiments, this diminution in the amplitude of the oscillations did not alter the number of oscillations which were performed in a given time. Dr. Seebeck found, that in alloying magnetic with non-magnetic substances, *he formed compounds which exercised no action on the needle.* The alloys which had particularly this singular property, were those consisting of four parts of antimony, and one of iron, or two parts of copper, and one of nickel. In these cases the Magnetism of the two ingredients must have been neutralized by their opposite actions.

(782) In consequence of these experiments of M. Arago, which were announced at the sitting of the French Institute, on the 22nd of November, 1824, and repeated in London, on the 7th of March, 1825, philosophers in every part of Europe turned their attention to the development of Magnetism by rotation. The most important results were obtained by Messrs. Babbage and Herschel. A horse-shoe magnet, which lifted 20 pounds, was made to revolve rapidly round its axis of symmetry, placed vertically with its poles uppermost. A circular disc of copper, 6 inches in diameter, and $\frac{1}{24}$th

of an inch thick, was suspended above the revolving magnet. As soon as the rotation of the magnet commenced, the copper began to turn in the same direction, at first slowly, but afterwards with an increased velocity. When the magnet was made to turn in an opposite direction, the disc of copper changed the direction of its motion also, and exhibited the same phenomena. Metallic plates 10 inches in diameter, and $\frac{1}{8}$-inch thick, when interposed between the magnet and the copper disc, did not sensibly modify the results, as M. Arago had observed. Glass produced no effect; but a sheet of tinned plate iron diminished greatly the influence of the magnet, while two such plates almost destroyed it. They found also that a disc of copper, 10 inches in diameter, and $\frac{1}{2}$-inch thick, and revolving with a velocity of 7 revolutions in a second, did not communicate any motion to a similar disc freely suspended above it.

(783) Messrs. Babbage and Herschel next sought to determine the effect produced by a solution of continuity in the metallic disc, upon which the revolving magnet acted. For this purpose a disc of lead 12 inches in diameter, and $\frac{1}{10}$th of an inch thick, was suspended at a given distance from a horse-shoe magnet, revolving with the ordinary rapidity, first in its entire state, and afterwards in the state shown in the annexed figures, the black lines in the direction of the radii being the planes where the lead was cut through. (Figs. 256, 257, 258, 259, 260.) The accelerating forces, represented

Fig. 256.

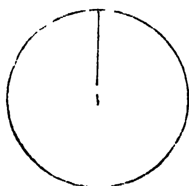


Fig. 257

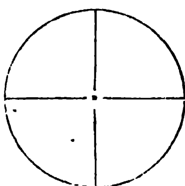


Fig. 258.

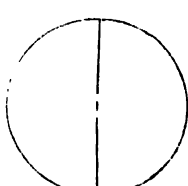


Fig. 259.

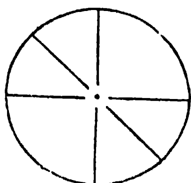
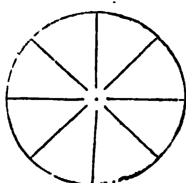


Fig. 260.



by $\frac{s}{t^2}$, where s is the number of the revolutions, and t the time employed, are as follow:—

Uncut disc.	Disc as in Fig. 256.	Disc as in Fig. 257.	Disc as in Fig. 258.	Disc as in Fig. 259.	Disc as in Fig. 260.
1258	1047	913	564	432	324

Effects similar, but differing in degree, were obtained with other metals: with soft tinned iron, the cutting produced a very slight diminution of effect, while in copper the same operation reduced the accelerating force in the ratio of 5 to 1.

They next tried the effect of filling up the cuts with different metals. A light upper disc suspended at a given distance above a revolving magnet, performed 6 revolutions in 54″ 8. When cut as in Fig. 260. its magnetic action was so weakened, that it took 121″ 3, to perform 6 revolutions; when the right open radial spaces were filled up with tin, its magnetic action was restored to such a degree, that it made 6 revolutions in 57″ 3. This fact is very interesting, as tin has less than half the energy of copper.

(784) M. Haldat made some very interesting experiments on this subject. He found that every needle, however weak its Magnetism, obeyed the action of the revolving disc; but that this action disappeared entirely when its polarity disappeared. He found it impossible to magnetize needles by the action of the revolving disc, however rapid; and in consequence of ascribing this effect to the want of coercitive power, he employed discs of iron and steel, both soft and hardened.

A disc of soft iron acted with more energy than one of copper, and with the same velocity, it dragged the needle twice the distance that a disc of brass did. Iron, strongly hammered, acted like soft iron, and was unable to give polarity to a steel needle; but a disc of untempered steel, $\frac{1}{25}$th of an inch thick, did not produce any appreciable effect on the magnetic needle, which, after a few irregular oscillations, maintained its ordinary position of equilibrium. Hence, he concluded, that the force which acted upon it was in the inverse ratio of the coercitive force. M. Haldat also found, that discs in a state of incandescence exercised the same action as those at the ordinary temperature.

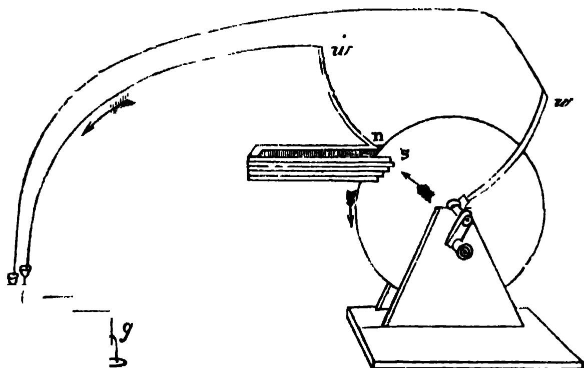
(785) Sir Wm. Snow Harris has since shown that several substances not supposed to contain iron, have the power of intercepting the influence of a revolving magnet, contrary to the observations of Messrs. Babbage and Herschel. A circular magnetic disc being delicately balanced on a fine central point by means of a rim of lead, was put into a state of rotation on a small agate cup, at the rate of 600 revolutions in a minute; and a light ring of tinned iron, also finely balanced on a central pivot, was placed immediately over it at about 4 inches distance, by means of a thin plate of glass, on which its

pivot rested. When the ring of tinned iron began to move slowly on its pivot by the influence of the magnet revolving below, a large mass of *copper* about *three* inches thick, and consisting of plates a foot square, was carefully interposed between the magnet and the iron ring. The interposition of the copper soon sensibly diminished the motion of the iron disc, and at length *arrested it altogether*. On again withdrawing the copper, the motion of the disc was restored; and the same effects were repeatedly obtained. In this experiment both the magnet and the disc were enclosed by glass shades, and supported on a firm base.

The same effects were produced by a mass of silver and zinc: but when their thickness was considerably diminished by removing the central plates, the motion of the disc was not impeded. A very great thickness of *lead* was necessary to stop the disc, in consequence, as Sir W. Harris supposes, of its magnetic energy being so much less than that of copper.

(786) It was about the period of these researches that Faraday made the capital discovery that a permanent current of Electricity may be produced by ordinary magnets. Fig. 261. represents the form of apparatus employed.

Fig. 261.

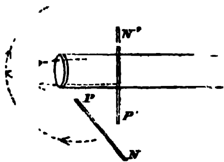


A copper plate mounted on an axis, is furnished with a handle for giving it motion; *w w*, are conducting wires,—the one retained in perfect metallic contact with the axis, and the other with the circumference of the disc. A powerful horse-shoe magnet is then placed so as to allow of the revolution of the disc between its poles, and the wires *w w*, are connected with the galvanometer, *g*; the wire *w*, is retained on the circumference of the disc, at the point between the poles of the magnet. When this machine is made to revolve from right to left, a current of Electricity from the centre to the circum-

ference is determined in the direction of the arrows, and the galvanometer is deflected accordingly. If the revolution of the disc, or the poles of the magnet be reversed, the electric current moves in an opposite direction;—while the plate is at rest, there is no disturbance of the needle of the galvanometer. The same effects are produced when electro-magnets, or coils of wire are substituted for the permanent magnetic poles; and when instead of employing a circular disc of metal, a strip of copper plate is placed between the magnetic poles, while two conductors from the galvanometer are held in contact with its edges, a current of Electricity is shown to be produced by simply drawing the slip of metal between the poles of the magnet.

(787) The *law* which governs the evolutions of Electricity by magneto-electric induction, is thus illustrated by Faraday.* If in Fig. 262 P N represent a horizontal wire passing by a marked magnetic pole, so that the direction of its motion shall coincide with the curved line proceeding from below upwards; or if its motion parallel to itself be in a line tangential to the curved line, but in the general direction of the arrows, or if it pass the pole in other directions, but so as to cut the magnetic curves in the same general direction, or on the same side as they would be cut by the wire if moving along the dotted curved line; then the current of Electricity in the wire is from P to N. If it be carried in the reverse directions, the electric current will be from N to P: or if the wire be in the vertical position P′ N′, and it be carried in similar directions, coinciding with the dotted horizontal curve so far as to cut the magnetic curves on the same side with it, the current will be from P′ to N′. If the wire be considered as a tangent to the curved surface of the cylindrical magnet, and it be carried round that surface into any other position; or if the magnet itself be revolved on its axis so as to bring any part opposite to the tangential wire; still if afterwards the wire be moved in the directions indicated, the current of Electricity will be from P to N; or if it be moved in the opposite direction, from N to P; so that, as regards the motions of the wire past the pole, they may be reduced to two, directly opposite to each other, one of which produces a current from P to N, and the other from N to P.

Fig. 262.

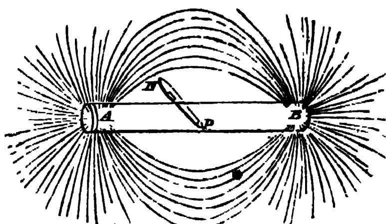


The same holds true of the unmarked pole of the magnet, except that if it be substituted for the one in the figure, then, as the wires are moved in the direction of the arrows, the current of Electricity would be from N to P, and when they move in the reverse direction, from P to N.

* Experimental Researches, 114.

(788) The direction of the current of Electricity which is excited in a metal when moving in the neighbourhood of a magnet is thus shown to depend upon its relation to the magnetic curves. Faraday, with his usual happy method of illustration, has given us this popular expression of it. Let A B (Fig. 263) represent a cylinder magnet, A being the marked, and B the unmarked pole; let P N be a silver knife-blade, resting across the magnet with with its edge upward, and with its marked or notched side toward the pole A; then in whatever direction or position this knife be moved, edge foremost, either about the marked or unmarked pole, the current of Electricity produced will be from P to N, provided the intersecting curves proceeding from A, abut upon the notched surface of the knife, and those from B upon the unnotched side; or if the knife be moved with its back foremost, the current will be from N to P, in every possible position and direction, provided the intersected curves abut on the same surfaces as before. A little model is easily constructed, by using a cylinder of wood for a magnet, a flat piece for the blade, and a piece of thread connecting one end of the cylinder with the other, and passing through a hole in the blade for the magnetic curves; this readily gives the result of any possible direction.

Fig. 263.



(789) From this discovery of Faraday's, then, viz., that when a piece of metal is passed before a single pole, or between the opposite poles of a magnet, electrical currents transverse to the direction of motion, are produced across it, a very satisfactory explanation of the phenomenon first observed by Arago, and afterwards examined in detail by Babbage, Herschel, and Harris can be given, without having recourse to the supposition of the formation in the revolving copper of a pole of the opposite kind to that approximated, surrounded by a diffuse polarity of the same kind. It is evident that as the plate revolves, in the neighbourhood of the magnet, or *vice versâ*, electrical currents are produced from the centre to the circumference, or from the circumference to the centre, in the direction of the radii; and the effect is precisely the same as in the electro-magnetic rotations, which, as we shall hereafter see, are governed by the following law: If a wire P N (Fig. 264) be connected with the positive and negative ends of a voltaic battery so that the positive Electricity shall pass from P to N, and a marked magnetic pole N, be placed near the wire, between it and the spectator, the pole will move in a direction

Fig. 264.

tangential to the wire, that is towards the right, and the wire will move tangentially towards the left, according to the direction of the arrows. So also when a plate of metal is made to rotate beneath a magnetic pole (suppose an N pole), a series of currents of Electricity will pass from the centre to the circumference of the plate if it is rotating in the direction of the hands of a watch, or from the circumference to the centre if it is rotating in the contrary direction; and it is at once evident that, according with the above law, both magnet and plate must move in the same direction; it is also evident why the phenomena cease when the magnet and metal are brought to rest, for then the electrical currents cease. The effects of a solution of the continuity of the disc in the experiments of Babbage and Herschel are likewise readily explained.

The question as to the universality of Magnetism has been placed in a new and intensely interesting light by the recent discoveries of Faraday and others relating to diamagnetic action, a full account of which we reserve for a future chapter.

(790) With regard to the influence of *heat* on magnetism, Mr. Christie, from a number of experiments made with the torsion balance, the needle being suspended by a brass wire $\frac{1}{460}$th of an inch in diameter, ascertained the following facts:—

i. Beginning with 3° Fahr. up to 127°, the intensity of magnets decreased as their temperature increased.

ii. With a certain increment of temperature the decrement of intensity is not constant at all temperatures, but increases as the temperature increases.

iii. From a temperature of about 80°, the intensity decreases very rapidly as the temperature increases; so that, if up to this temperature, the differences of the decrements are nearly constant, from this point the differences of the decrements also increase.

iv. Beyond the temperature of 100°, a portion of the power of the magnet is permanently destroyed.

v. On a change of temperature, the most considerable portion of the effect on the intensity of the magnet is produced instantaneously, showing that the magnetic power resides on, or very near the surface.

vi. The effects produced on soft iron by changes of temperature, are directly the reverse of those produced on a magnet; an increase of the temperature causing an increase in the magnetic power of the iron. This was observed between the temperatures of 50° and 100° Fahr. Mr. Christie regards this as a strong argument against

the hypothesis, that the action of iron upon the needle arises from the polarity which it receives from the earth.

(791) In the year 1820 Sir David Brewster announced the discovery of two poles of maximum cold on opposite sides of the north pole of the earth, and he was led to entertain the opinion that there might be some connexion between the *magnetic* poles and those of maximum cold. "Imperfect," says he, "as the analogy is between the isothermal and magnetic centres, it is yet too important to be passed over without notice. Their local coincidence is sufficiently remarkable, and it would be to overstep the limits of philosophical caution, to maintain that they have no other connexion but that of accidental locality; and if we had as many measures of the mean temperature as we have of the variation of the needle, we might determine whether the isothermal poles were fixed or moveable." The connexion between the poles of maximum cold and those to which the isodynamical magnetic lines are related was considered as a probable supposition by the late Dr. Dalton. Other philosophers have expressed similar opinions. Dr. Traill says, "The disturbance of the equilibrium of the temperature of our planet by the continual action of the sun's rays on its inter-tropical regions, and by the polar ices, must convert the earth *into a vast thermo-magnetic apparatus;* and the disturbance of the equilibrium of temperature, even in stony strata, may elicit some degree of Magnetism." Mr. Christie also thinks it not improbable "that difference of temperature may be the primary cause of the polarity of the earth, though its influence may be modified by other circumstances." And in his treatise on "Thermo-Electricity," M. Œrsted remarks, "that the most efficacious excitation of Electricity upon the earth appears to be produced by the sun producing daily evaporation, deoxidation, and heat, all of which excite electrical currents." . . . "Thus the earth seems to have a *constant magnetic polarity* produced in the course of time by the electrical currents which surround it, and a *variable Magnetism* produced immediately by the same current."

(792) Sir Wm. Snow Harris's Memoirs were published in the Transactions of the Royal Society of Edinburgh for 1827, and in the Philosophical Transactions for 1831. In the first, entitled "Experimental Inquiries concerning the Laws of Magnetic Forces," he shows by a beautiful series of experiments, that the magnetic development in masses of iron by induction is, *cæteris paribus, directly proportional to the power of the inductive force, and inversely as the distance;* and that the forces which magnets develope in a mass of iron at a given distance, within certain limits, may be taken as a fair measure of their

respective intensities; he also shows that the absolute force of attraction, exerted between a magnet and a piece of iron, varies with the power of the magnet, and consequently with the force induced in the iron, *cæteris paribus;* and that when the force induced in the iron is a constant quantity, while its distance from a temporary or permanent magnet is variable, *the absolute force varies with the distance.* Sir William made a number of nice experiments on the absolute force of attraction and repulsion between two magnetized bodies, which he found to be in the inverse ratio of the square of the distance. When in the case of attraction, the magnets however were nearly approximated in relation to their respective intensities, the increments in the forces began to decline, and in some instances at near approximations, the absolute force was in the simple inverse ratio of the distance. In the experiments with the repelling poles, the deviations from the regular force were still more considerable, and what is curious in this case, the force became less and less until the polarity of the weaker magnet appeared to be so counteracted by induction *that the repulsion was at length superseded by attraction.* The law according to which the forces are developed in different points of the longitudinal magnetic axis between the centre and poles of a magnet he found to vary directly as the square of the distance from the magnetic centre, a law which is uniform in bars of steel regularly hardened and magnetized throughout. This law of distribution is exactly the same as that which had been given by Hansteen. Sir W. Harris repeated the experiment of Mr. Christie, and found with that philosopher that the oscillations of a magnetic bar were diminished in bright sunshine, but he found all differences to disappear when the needle was made to oscillate in an exhausted receiver, from which it would appear that Mr. Christie's results must have been owing to currents of air.

MAGNETISM (CONTINUED).

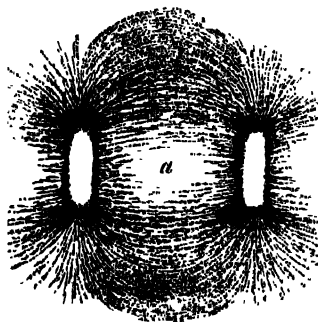
CHAPTER XIV.

General Facts and Principles—Duality of the Magnetic Force—Magnetic Curves—Haldat's Magnetic Figures.

(793) The native magnet, or natural loadstone, is an ore of iron, consisting chiefly of the two oxides of that metal, together with a small proportion of quartz and alumina. It is usually of a dark grey hue, and has a dull metallic lustre. It is found in considerable masses in the iron mines of Sweden and Norway, and also in different parts of Arabia, China, Siam, and the Philippine Islands. Small loadstones have occasionally been met with among the iron ores of England. The smallest loadstones have generally a greater attractive power, in proportion to their size, than larger ones. They have been found of such a strength, that, though weighing only about ·25 grains, they could lift a piece of iron *forty-five* times heavier than themselves. Sir Isaac Newton had a small specimen, set in a ring, which was capable of lifting 746 grains of iron, or 250 times its own weight; and it is stated by Cavallo, that he has seen a loadstone which weighed only 6½ grains, which lifted a weight of 300 grains.

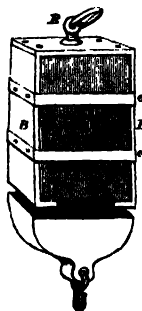
(794) If we immerse a natural loadstone—no matter of what shape—in a quantity of clean iron filings, we shall find that there are two points exactly opposite each other, on which the filings are accumulated more abundantly than on any other place, assuming the form shown in Fig. 265, the lines diverging from the ends of the magnet in *curves*, the centre *a*, being nearly free from them. These are called its poles; and if we balance a small needle of iron on a pivot, and bring it near either of these poles, we shall find that it will be attracted towards it; or, conversely, if we suspend the loadstone by a fine fibre, and bring into the vicinity of its poles, a

Fig. 265.



piece of soft iron, it will be drawn towards the iron; a reciprocal attraction is exerted between them, action and re-action being equal and opposite.

Fig. 266.

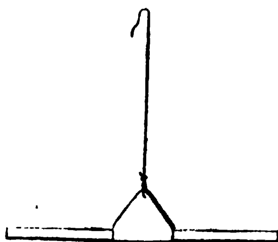


The power of the natural magnet is greatly increased by adapting two pieces of flat soft iron to its poles, and enclosing it in a silver or brass case. In Fig. 266 a magnet thus *armed*, is shown: A is the loadstone; BB, two pieces of soft iron placed against its opposite poles, the lower ends turning inwards, and fastened by transverse bars of copper, *c c*, to the brass case which surrounds the sides and upper part of the stone. In the top of the box is inserted a ring, R, for the purpose of suspending the whole; and to the lower part of the armature is adapted a piece of soft iron, with a hook, on which is hung as much weight as the strength of the magnet will bear.

(795) When a piece of steel has been rendered magnetic, it exhibits the same properties as the natural loadstone; and since we are in the possession of a variety of methods of communicating to it this state, the artificial magnet is always employed in experimental investigations. We shall describe some of the most approved methods of magnetizing iron presently: in the meantime, we shall only observe that, for the exhibition of the experiments we shall first have to allude to, the following simple and ready method will be found amply sufficient for communicating to small bars of steel the requisite degree of Magnetism. (Scoresby.)

Break off sharply with a pair of pliers, about 3 inches of a thick steel knitting needle, and give it several smart blows with a hammer, while its smooth and rounded end rests on the knob of a poker held vertically between the knees, the poker itself having been previously hammered while in this position. The wire will, by this treatment, become magnetic. The downward end, while under percussion, being a *north pole*. If the bar to be magnetized be placed between two iron rods (the lower one having been previously hammered) and the hammer then applied to the top of the pile, increased effects are obtained.

Fig. 267.

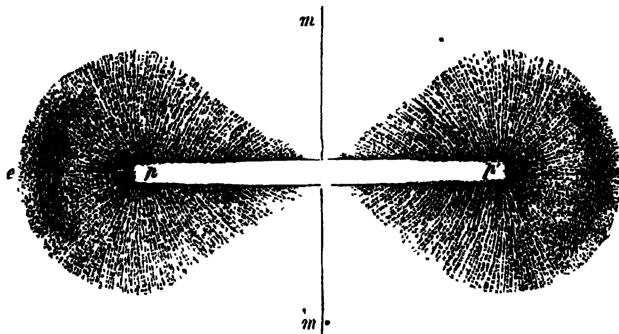


If the bar which has been thus treated, be suspended horizontally in a little stirrup of paper or metal by a fibre of silk, (Fig. 267), and if all bodies of a ferruginous nature be removed from its vicinity, it will, after a few oscillations, take

up a position nearly north and south; and if it be disturbed from this position, and placed in any other, it will not remain there; but as soon as it is at liberty to move, it will resume its former position. It will also possess the power of communicating Magnetism to hard steel *permanently*, and to soft iron *temporarily*, the degree of strength, of course, depending on its own power, and with respect to the steel, on the time which it is suspended. If two magnetized bars be poised and placed in different positions respecting each other, it will be found that in some cases they appear to be attracted towards each other, while in others they manifest a mutual repulsion. This, however, does not happen capriciously; the two north poles and the two south poles invariably repel each other; but the north pole of one magnet always attracts, and is of course attracted by the south pole of the other. An excellent extemporaneous pivot for a needle or bar may be formed by inverting a common precipitating glass on a pivot, and laying the bar on it. The bar may likewise be laid upon the centre of a clean watch-glass, on which, because of the curvature of the glass, it will rest as on a point, and perfect freedom of motion will be obtained by tapping the table near the watch-glass with the knuckle.

(796) If the bar thus rendered magnetic be sprinkled over with, or rolled into, fine iron filings, the filings will be observed to adhere to it, in the form of bristling tufts (Fig. 268), but by no means in a uniform manner: at the extremities, *e e'* the iron filaments will be

Fig. 268.



very long, standing out perpendicularly from the surface. As the centre of the bar is approached they will become shorter, gradually taking up a more and more inclined position, and adhering in smaller and smaller tufts as the central line *m m'* is approached. In the immediate neighbourhood of this line no filings are attracted; this, therefore, is called the *neutral line*, and the two halves of the bar *p p'* are called the *magnetic poles*. Every magnet, natural or artificial,

possesses essentially this neutral line and these magnetic poles; it sometimes, however, happens that a magnetized bar possesses more than two poles, two or more poles alternating between those situated at either extremity of the bar. A magnet in this condition is said to have "*consecutive poles.*"

(797) In order to communicate Magnetism from a natural or artificial magnet to unmagnetized iron or steel, it is not necessary that the two bodies should be in contact. The communication is effected as perfectly, though more feebly, when the bodies are separated by space. Thus, in Fig. 269, if the *north pole* of an artificial steel magnet *A*, be placed near the extremity *S*, of a piece of soft iron *B*, the end *s*, will instantly acquire the properties of a *south pole*, and the opposite end *n*, those of a north pole. The opposite poles would have been produced at *n* and *s*, if the south pole *s*, of the magnet *A*, had been placed near the iron *B*.

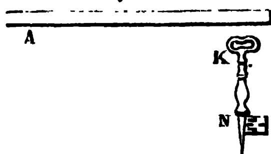
Fig. 269.

In like manner, the iron *B*, though only temporarily magnetic, will render another piece of iron *C*, and this again, another piece *D*, temporarily magnetic, north and south poles being produced at *n′*, *s′*, and *n″*, *s″*.

(798) Here we cannot fail to observe a pointed analogy between the phenomena of magnetic attraction and repulsion, and those of electrical. In both there exists the same character of double agencies of opposite kind, capable, when separate, of acting with great energy, and being, when combined together, perfectly neutralized, and exhibiting no signs of activity. As there are two electrical, so there are also two magnetic powers; and both sets of phenomena are governed by the same characteristic laws. So also in the last experiment, the Magnetism inherent in *B*, *C*, *D*, is said to be *induced* by the presence of the real magnet *A*; and the phenomena are exactly analogous to the communication of Electricity to unelectrified bodies by induction, the positive state inducing the negative, and the negative the positive, in the parts of a conductor placed in a state of insulation near an electrified body.

(799) A simple experiment will satisfactorily show that soft iron possesses magnetic properties, while it remains in the vicinity of a magnet. Let A (Fig. 270) be a magnet, and K a key, held either horizontally near one of its poles, or near its lower edge. Then if another light piece of iron, such as a small nail, be applied to the other end of the key, the nail will hang from the key, and will continue to do so while

Fig. 270.



the magnet is slowly withdrawn; but when it has been removed beyond a certain distance, the nail will drop from the key, because the Magnetism induced on the key becomes at that distance too weak to support the weight of the nail. That this is the real cause of its falling off, may be proved, by taking a still lighter fragment of iron, such as a piece of very slender wire, and applying it to the key. The Magnetism of the key will still be sufficiently strong to support the wire, though it cannot the nail; and it will continue to support it, even when the magnet is yet further removed; it at length, however, drops off.

If the key be held above a portion of iron filings, they will not be attracted by it; but if the magnet be then brought near the ring of the key, as in the figure, the iron filings will instantly start up, and be attracted by the key.

(800) It has been observed, that in all cases where a magnet attracts iron, a reaction takes place, the iron attracting the magnet; it is the same with a bar of iron on which Magnetism has been induced. It reacts upon the magnet, which induces its Magnetism, and increases its magnetic intensity. Hence, we derive a distinct explanation of the remarkable facts, that a magnet has its power increased by having a bar of iron placed in contact with one of its poles, and that we can gradually add more weight to that which is carried by the magnet, provided we make the addition slowly, and in small quantities, the power of the magnet being increased by the reaction of each separate piece of iron that it is made to carry.

These facts enable us to explain the phenomena of magnetic attraction and repulsion. The magnet attracts a piece of iron by inducing an opposite polarity at the end in contact with it; and the two opposite principles attract each other. In like manner, the north pole of one magnet attracts the south pole of the other; and the north and south poles repel each other, in consequence of the attraction and repulsion of the opposite and similar principles. The attraction of iron filings is explained in the same way. The particle of iron next the magnet, has Magnetism induced on it, and it becomes a minute magnet, like *B*, Fig. 269. This particle again makes the next particle a magnet, like *C*, and so on, the opposite polarity in each particle of the filings attracting one another, as if they were real magnets.

(801) In comparing the amount of the *attractive* force of two *dissimilar* poles of two magnets, with the amount of the *repulsive* force of the two similar poles, it has been found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process above described. When the

two attracting poles are in contact, each magnet tends to increase the power of the other, by developing the opposite magnetic states in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, the action of each half brought into contact,has a tendency to develope in that half, a Magnetism opposite to that which. it really possesses, and thus to diminish the two similar principles, and weaken their repulsive power. This injurious influence of opposite poles upon the repulsive power of the magnets in action, is well exhibited when one of the magnets is very powerful, and the other very weak. When the two similar poles are held at a moderate distance, a repulsion is distinctly exhibited; but when they are brought into contact, the stronger *attracts* the weaker magnet, an effect which is produced by its actually destroying the similar weak Magnetism in in the half next to it, and inducing in that half the opposite Magnetism, which of course occasions attraction.

(802) The law regulating the variation of the intensity of the magnetic forces, both attractive and repulsive at different distances, has been submitted to careful investigation by several eminent mathematicians, and the general result has been it is the same that obtains in Electricity and in gravitation, viz., that the intensity of the force by which magnetic polarities act on each other is inversely as the square of the distance, a law which seems common to all forces emanating in every direction from a central agent.

(803) The process of induction is in its operation independent of the relative positions of the magnet and the soft iron. Thus in Fig. 271, let A be the permanent steel magnet, and B and C pieces of soft iron. The two ends *s s* will become south poles, and the opposite ends *n n*, north poles, under the inducing influence of A; but C will become more powerfully magnetic than B, because from its inclined position the pole S of the steel bar A begins to exert an inductive influence on *n*. From this it is evident that the most favourable position in which a bar can be placed for receiving the full inductive influence of both poles is that of parallelism, as shown in Fig. 272. The effects become somewhat complicated when the inducing bar is brought either very near, or in contact with, the iron bar in other positions than the ends. Thus if we bring the north end of a magnetized

Fig. 271.

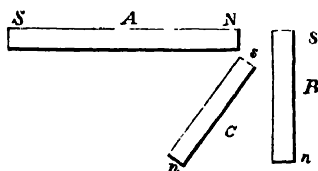
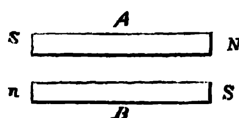
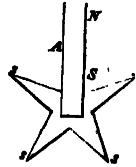


Fig. 272.



bar opposite the centre of a soft iron rod, the two ends of the rod will become temporarily two north poles, a south pole being induced in the centre. In like manner the star-shaped piece of iron (Fig. 273) will have south poles at *s s s s*, on bringing the S pole of the bar S opposite its centre. If a circular iron plate be substituted for the star, then every part of its circumference will have a southern polarity.

Fig. 273.



(804) The experiment illustrated in Fig. 274, shows the operation of magnetic induction in a very instructive manner. Several soft iron wires are suspended from the N pole of a strong bar magnet. The wires immediately become temporarily magnetic, their S poles being determined towards the N pole of the inducing bar, and their opposite extremities becoming *n* poles. Both ends have a natural tendency to repel each other, but the S ends are prevented from yielding to their repulsive influences in consequence of their strong adhesion to N. The *n* poles not being under the influence of this restraining power avoid one another, as represented in Fig. 274. Again, in the following experiment of Cavallo, we have well illustrated the mutual repulsive action of similar poles. Two pieces of soft iron (Fig. 275) are suspended by threads from a ring or hook, so as to have free liberty of motion, on bringing either, say the N pole of a strong bar magnet, at a certain distance below the wires, the wires become inductively magnetic, and their similar S poles being determined towards N, a mutual repulsion is set up. If now the magnet A be approached very near to the wires, the repulsion of the *s s* ends of the wires gives place to an apparent attraction; this is caused by the stronger attraction of A, for both wires overcoming their own mutual repulsions; the repulsion of the *n* ends of the wires is, however, now rendered evident, and the nearer the inducing magnet is brought to the wires the stronger will this repulsion be manifested. On removing A, the wires immediately collapse, and fall into a parallel and vertical position, the Magnetism induced upon them being merely of a temporary nature. When fine steel needles

Fig 274.

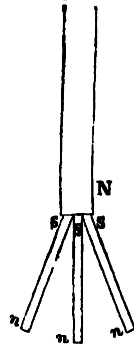
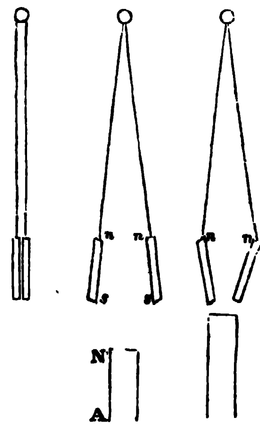


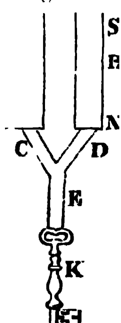
Fig. 275.



are substituted for soft iron wires, it often happens that they acquire a certain amount of permanent Magnetism, in which case they, of course, continue to repel each other after the removal of the magnetic bar.

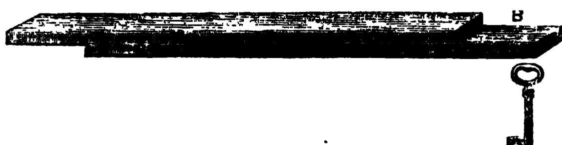
(805) The following experiment of Dr. Robison is likewise instructive as showing the neutralization or destruction of induced Magnetism by two equal and opposite magnetic actions. A forked piece of soft iron, C D E, is suspended by one of its branches from the N pole of the magnetic bar, A B; if the power of B be pretty strong, it will induce sufficient temporary Magnetism in C D E to enable it to hold in suspension the key K; but if we now bring into contact with the other branch of the fork the S pole of a second magnetic bar, the key will immediately drop off. The reason is evident: the N pole of B induces a N pole at the lower end E of the fork; hence its power of sustaining the key; but the S pole of A tends to give a southern polarity to the same end, and the two actions mutually destroy or neutralize each other.

Fig. 276.



Again,

Fig. 277.

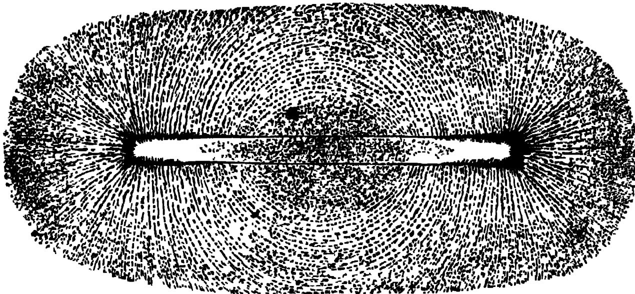


suspend any object of soft iron, as a key, from either pole of the magnetic bar A, then gradually slide over A a second similar bar B, taking care that the opposite poles of the two bars shall come into contact when the end of B arrives within a certain distance of A, the key will fall off as if the bar had lost its magnetic power; this, however, is not the case, for on removing B the key will be again supported.

(806) We have seen the close analogy which exists between the phenomena of Electricity and those of Magnetism, as far as relates to the law of action, and the influence of induction, but beyond this point it fails us entirely. No natural or artificial magnet has ever been seen with only *one pole*, or with one kind of Magnetism; Electricity on the other hand, whether positive or negative, is not only capable of being excited by induction, but it may be actually transferred from one body to another. A body may without difficulty be electrified positively or negatively as has been shown in a previous

chapter (30—42); but with Magnetism there is never any transfer of properties, but only the excitation of those which were already inherent in the body operated on. If we examine a magnetized bar, by laying it on a table, covering it with a sheet of white paper, or with a plate of thin glass, and then sifting some fine iron filings over it from a muslin bag, the filings will, on gently tapping the table, be found to arrange themselves round and about the poles of the magnet in a very beautiful manner, forming a succession of curves known as the "magnetic curves," (Fig. 278), or "the curved lines of magnetic

Fig. 278.

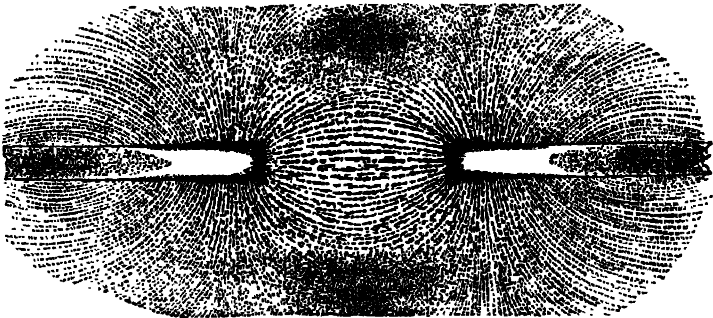


force" (Faraday). On examining these curves, it will be found that the force decreases gradually from the poles towards the centre, or some point intermediate between the two poles, where it vanishes altogether. This is the neutral point, or as it may be called the *equator* of the magnet. If we break the magnet at this point, we shall not find a north polar Magnetism distributed uniformly over one portion, and a south polar Magnetism over the other, but each half will be a perfect magnet in itself, and if examined by iron filings, will be found to exhibit the "curved lines of magnetic force" as perfectly as the unbroken bar; the same will be the case if the pieces be again broken—other magnets will be formed, each having an equator and two poles; and in like manner, however numerous and minute the fragments into which a magnet may be divided, each part will be still a complete magnet with two poles and a neutral point.

(807) Beautiful visual evidence of the existence of two distinct magnetic forces — of their mutual attractions, repulsions, and neutralization—are afforded by the phenomena presented when iron filings are submitted to the influence of the opposite and similar poles of two pairs of magnetic bars. Let the two dissimilar poles of two powerful bars be placed in the same line, about 1½ or 2 inches apart, and let the filings be sifted through a sieve on a frame of drawing paper, placed over them, the filings will arrange themselves as shown in Fig. 279, the curved and straight

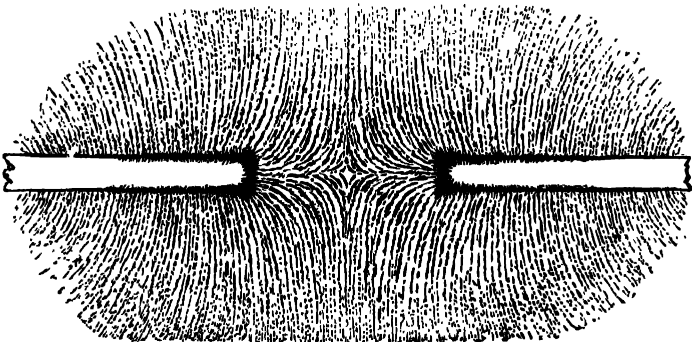
lines of magnetic force issuing from similar points of each bar joining the two poles,

Fig. 279.



and showing reciprocal attraction. Then let the two similar poles be placed opposite each other and the filings again sifted over them; evidence of mutual repulsion will now be obtained, the lines of force being apparently conflicting, as shown in Fig. (280.)

Fig. 280.

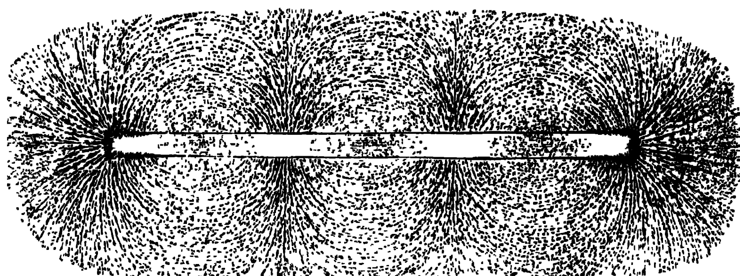


It sometimes happens, that either from some peculiarity in the structure of the bar, or from some irregularity in the magnetizing process, a magnet is met with having more than two poles. This curious condition is readily detected by examining the magnetic curves into which iron filings are thrown when sprinkled over the bar. They will be found to be distributed in the manner shown in Fig. 281.

A magnetic bar in this condition is said to have *consequent* or *consecutive* poles.

The fundamental properties of the magnetic curves were investigated mathematically by Dr. Roget (*Journal of the Royal Institution, Feb.,* 1831). He describes them as having the following remarkable

Fig. 281.



property, viz., that the difference of the cosines of the angles, which lines drawn from any point in the curve to the two poles, make with the axis, taken on the same side, is constant; and he constructed a system of rulers by which these curves may be mechanically delineated.

(808) *Sustaining Power of Electro-Magnets.*—The experiments of Jacobi and Lenz (*Pogg. Ann.* xlvii., 403) led them to the conclusion that under conditions in other respects similar, the total attraction, *i.e.*, the mutual adherence of two straight cylindrical electro-magnets, or of one electro-magnet and one armature of soft iron, is proportional to the *square of the strength* of the current; to this proposition Müller assents (*Ann. rep. Prog. Chem.* 1850). According to Barral (*Comptes Rendus*, xxv. 757), the attraction increases with the weight of the keeper, and reaches its maximum when the electro-magnet and keeper are of equal weight. The experiments of Dub agree with this indication only so far that for a given electro-magnet, and a given diameter of keeper, a certain amount of sustaining power cannot be exceeded. This limit seems to depend more upon the length than on the weight, and to be more slowly attained the greater the strength of the current. He corroborated the result that the single coils contribute more to the development of the magnetic intensity of the poles, the nearer they are to the latter; and that when the coils are arranged in different systems of equal power, the lifting power, with a constant current, is proportional to the square of the number of systems in action.

The distribution of Magnetism in the polar surfaces of an electro-magnet was determined by Von Kolke (*Pogg. Ann.* lxxxi., 321). The magnetic force in any given zone of the surface which intersects the axis of the magnet at right angles, is always greater at the edges than upon the surfaces; in fact, in the case of a large horse-shoe electro-magnet, he found the force almost twice as great at the rim as at the centre. In consequence of the action of the poles upon each other, the weakest point was not found to be at the exact centre, but

approached it more and more, the less the two limbs could act inductively upon each other. The method of measurement adopted was that proposed by Plücker, viz., by determining by means of a balance, the weight necessary to separate a small-pointed iron cylinder from a given point on the surface of the magnet. For all practical purposes the numbers thus obtained may be taken to represent the magnetic intensity of the places tested.

The results obtained by Pfaff are the following (*Peschel*) :—

1°. The amount of suspensive force is immediately dependent on the intensity of the electric current which circulates about the iron; and the intensity of the Magnetism excited in the soft iron is exactly proportional to that of the electric current.

2°. The intensity of the current continuing the same, the magnet's suspensive force increases with the number of turns made by the wire; or the total effect of all the coils is equal to the sum of their effects, if taken singly.

3°. The attractive force of an electro-magnet increases as the mass of the iron composing it, and this increase is proportional to the diameters of the iron cylinders, their lengths being equal.

4°. The purer and softer the iron, and the more homogeneous the mass, the stronger the Magnetism it is capable of receiving.

5°. The form of the iron influences its suspensive power, cylinders carry greater weights than rectangular bars, and a hollow cylinder, from which a portion has been cut away so as to form a long horseshoe magnet, when viewed in the direction of its axis, but a very short one if taken, as to its height, is capable of receiving a very great suspensive force; and lastly, a slight curvature of the polar surface adds considerably to its power.

(809) We are indebted to M. Haldat, of Nancy, for the discovery of magnetic figures analogous to those first produced with Electricity by M. Lichtenberg, and which may easily be exhibited. For this purpose he employs plates of steel, from 8 to 12 inches square, and from $\frac{1}{20}$th to $\frac{1}{8}$th of an inch thick. The plates which he used were of that kind of steel which is used for the manufacture of cuirasses; so that it did not require to be tempered, being sufficiently hard to preserve the Magnetism communicated to it. Figures of any kind may be traced on the surface of the steel plate, either by one magnet or by several combined, and the best form for this purpose is that in which the poles are rounded. In this way we may write on a steel plate the name of a friend, or sketch a flower or figure, with the extremity of a magnet. If it is the south pole that we use, all the traces that we make will have north polar magnetism; and if we shake steel filings on the plate out of a gauze bag, the

filings will arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent in vacant steel the name which has been written, or the flower or figure which has been sketched. " These figures," says M. Haldat, " have a perfect resemblance to those which are formed on the surface of non-magnetic plates, viz., wood, card, glass, or paper, under which a magnet is placed. The resemblance between the two sorts of figures, when the magnets and the parts magnetized have the same form, is not only exact in the whole figure, but likewise in the smallest details. The filings collect at the parts where the Magnetism is most intense, and they arrange themselves in pencils and radii. These curves, and pencils, and rays, so similar at the two poles of the same magnet, have such a resemblance that they do not allow us to distinguish the two parts from one another."

(810) In sifting the iron filings upon the steel plate, a general vibration of the plate, by tapping its edge with the ring of a small key, will assist the filings in taking their proper places; but we must avoid such vibrations as will produce regular acoustic figures, unless we wish, as M. Haldat has found to be practicable, to unite the magnetic with the acoustic figures, which produces very interesting and varied forms.

In order to remove the Magnetism from the steel plates, they may be heated over charcoal, till they become of the straw-coloured temperature; and to render the repolishing of them unnecessary, M. Haldat tins them, and the temperature at which the tin melts, when it is required to efface the Magnetism, indicates the necessary heat.

(811) As the figures traced on the steel are nothing more than magnets of different forms, and are surrounded on all sides with a substance capable of acquiring the Magnetism which may be developed by communication, we might expect, as M. Haldat remarks, that this means of communication between the opposite poles of the magnets would bring them into a neutral state. This, however, is not the case; and the portion of the metal which surrounds the magnetic figure, performs the part of the *armature* of a loadstone, and the Magnetism is thus kept up.

The figures might be rendered permanent, by covering the steel plate either with a gummy or balsamic solution, which will become hard by exposure to the air; or with a coating of some easily melted substance which becomes fixed at ordinary temperatures. If we sift the iron filings on the steel plate when covered with such a fluid, the filings will take their magnetic position round the traced lines, and will become fixed by the induration or solidification of the fluid coating.

Mr. Faraday gives (*Ex. Researches*, Series 29), the following process for *fixing* the designs on the paper: A piece of cartridge paper is well moistened with a solution of one part of gum in three or four of water, by means of a broad camel's hair brush, and after wafting it through the air once or twice to break the bubbles, it is laid carefully on the filings, then covered with ten or twelve folds of equable soft paper; a board is placed over the paper, and a half-hundred weight on the board for thirty or forty seconds; or with a large design, the hand should be applied so as to rub with moderate pressure all over the surface equably in one direction. If after that, the paper be taken up, all the filings will be found to adhere to it, and when dry are firmly fixed. If a little solution of red ferro-prussiate of potash, and a small proportion of tartaric acid is added to the gum water, a yellow tint will be given to the paper, and Prussian blue will be formed under every particle of iron, and then if the filings be removed, the designs still remain recorded. When the designs are to be preserved in blue only, the gum may be dispensed with.

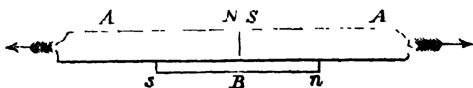
MAGNETISM—Continued.

CHAPTER XV.

Methods of making artificial magnets—Processes of Knight, Scoresby, Duhamel, Michell, Canton, Epinus, Coulomb, Barlow, Elias—Circumstances which affect the energy of artificial magnets—Laws of magnetic combinations—Useful application of the magnetic powers—Laws of magnetic force.

(812) *Methods of making Artificial Magnets.*—For the impregnation of small bars or plates, the following simple process will be effectual. Draw the bar (which should be of a well hardened steel, tempered by plunging it at a cherry-red heat into cold water, and afterwards polished) a few times across the poles of an armed natural loadstone, or an artificial horse-shoe magnet, taking care not to remove the bar from either extremity of the inducing magnet, and to terminate the operation when its extremities are equi-distant from either pole of the horse-shoe, that is, when the poles of the latter are as nearly as possible at the centre of the bar. In this position remove it, and it will be found to have acquired all the magnetic power it is capable of receiving. For larger bars, a great variety of processes have been invented. The first of these was that of Mr. Knight. This method which was kept a secret during his lifetime, but which was made public after his death by Mr. Wilson, consisted in placing the bar to be magnetized, after having tempered it at a cherry-red heat, under the poles N S, (Fig. 282) of two equal magnets. These magnets are then separated in opposite directions, S A, N A, so that the south pole of the one should pass over the north polar half, B n, of the bar, B, and the north pole, N, of the other half over the south polar half, B s, of B; this operation is repeated several times till the magnetization of the bar B is fully developed.

Fig. 282.

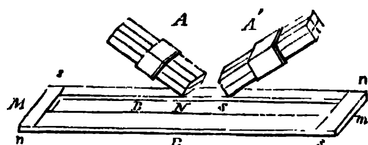


(813) This method is modified by Scoresby (*Magnetical Investigations*, 1839), by placing the bar to be magnetized, *above*, instead of *beneath*, the magnets employed in the operation, by which great facility is given for the performance of the requisite manipulations, and for the maximum development of the magnetic condition. The plate to be magnetized is laid flat upon the magnets, so as to extend equally over the surface of both. The bars are then drawn asunder,

till the plate just rests with its extremities in contact with the extreme poles of the magnets, and then it is slid off sideways, and removed to some distance, preserving the parallelism of its position with that of the magnets, till these are restored to the proximity with which the operation commenced. The process is repeated with the other side of the plate in contact with the magnets, and in the case of thin small plates—sea compass-needles for instance—the condition of saturation is found to be obtained. Usually, however, four strokes are given, two on each side; and in hard short bars, six or eight strokes are given, partly on the edges. A dozen compass-needles may thus be magnetized to saturation in five or six minutes, and by means of a pair of strong two-feet magnets, compass needles or dipping needles of the usual form, can be brought to their maximum power without removing their agate caps or centres

(814) Soon after the publication of Dr. Knight's method, small bars thus magnetized were distributed all over Europe, and were eagerly sought after by the cultivators of natural philosophy. When the process, however, was applied to bars of large size, it was found to be defective; philosophers therefore renewed their efforts to devise methods of greater and more universal efficacy. The next improvement was made by M. Duhamel, of the Academy of Sciences, in conjunction with M. Antheaume. The process is represented in Fig. 283. The bars *B B* to be magnetized, are placed parallel to each other, and have their extremities united by two pieces, *Mm*, of soft iron, at right angles to the bars; two strong magnets, or two bundles of small bar magnets, *A A′*, having their similar poles together, are placed as in the figure, at an angle of about 90°, or inclined at 45° to the bar *B*, and then separated from each other, as in Dr. Knight's method; the same operation is repeated on the other bar *B*, and continued alternately on both, till the Magnetism is supposed to be completely developed in both bars. When *A A′* are placed on the second bar *B*, the disposition of the poles must be reversed; the pole that was formerly to the right hand being now turned to the left. The two bars *B B* are then turned, so that the undermost faces are uppermost, and the same process carried on as before.

Fig. 283.

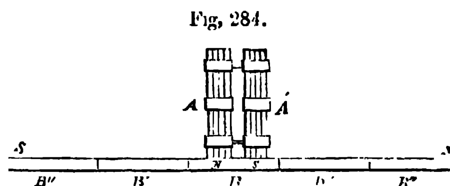


The peculiarity of Duhamel's process consists in the employment of the pieces of iron *M m*, and in the use of bundles of small bars, which are more efficacious than two single ones of the same size. In

proportion also as the steel bars acquire Magnetism, the connecting pieces participate in the acquisition of a similar power, and serve to retain it in the bars themselves; just as the Electricity which is imparted to the inner coating of a Leyden jar, is retained by the reciprocal influence of the induced, and contrary Electricity of the outer coating. The Magnetism of the bars is retained by a similar influence, and greater facility is thus afforded to increase its amount, by the subsequent additions it is receiving from the action of the magnets, as they pass along the surface.

(815) About the same time that Duhamel was occupied with this subject, Mr. Michell, of Cambridge, and Mr. Canton, were separately engaged in the same inquiry. Mr. Michell published his method in 1750, to which he gave the name of *method by double touch*. Having joined together, at the distance of ¼th of an inch, two bundles of strongly magnetized bars, *A A′* (Fig. 284), their opposite poles, *N S*, being together, he placed five or more equal steel bars, *B B′ B′ B″ B″*, in the same straight line, and resting the extremity of the bundle of magnets, *A A′*, upon the middle of the central bar, *B*, he moved them *backwards and forwards* throughout the whole length of the line of bars, repeating the operation on each side of the bars, till the greatest possible effect was produced. By this method Mr. Michell found that the middle steel bars, *B B′ B′*, acquired a very high degree of magnetic virtue, and greater than the outer bars, *B″ B″*; but by placing these last bars in the middle of the series, and repeating the operation, they acquired the same power as the rest. Mr. Michell states that two magnets will, by his process of *double touch*, communicate as strong a magnetic virtue to a steel bar as a single magnet of five times the strength when used in the process of single touch. The bars *A A′* act with the sum of their powers in developing Magnetism in all parts of the line of the bars between them, and with the difference of their powers in all parts of the line beyond them. The external bars act the same part in this process as the two pieces of soft iron in the method of Duhamel.

Fig. 284.



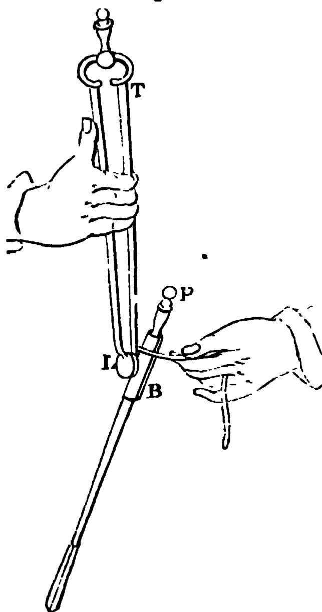
(816) Mr. Canton placed the bars as in Duhamel's method, joined by pieces of soft iron. He then applied Michell's method of double touch, and afterwards he separated the two bundles of magnets, *A A′*; and having inclined them to each other, as in Duhamel's method, he made them rub upon the bar from the middle to

its extremities. The peculiarity of Canton's method is the union of these two processes; but Coulomb and others are of opinion that the latter part of the process is the only effectual one.

(817) In order to make artificial magnets, without the aid either of natural loadstones or artificial magnets, Mr. Canton gives the following detailed process:—

He takes six bars of soft, and six of hard steel; the former being smaller than the latter. The bars of *soft* steel should be 3 inches long, $\frac{1}{4}$th of an inch broad, and $\frac{1}{20}$th thick; and two pieces of iron must be provided, each having half the length of one of the bars, and the same breadth and thickness. The bars of *hard* steel should be each $5\frac{1}{2}$ inches long, $\frac{1}{2}$ an inch broad, and $\frac{3}{20}$ths of an inch thick, with two pieces of iron of half the length, and of the same breadth and thickness.

Fig. 285.



All the bars being marked with a line quite round them at one end, take an iron poker and tongs, or two bars of iron (the larger and the older the better), and fixing the poker upright, as in Fig. 285, hold to it with the left hand near the top, P, by a silk thread, one of the soft bars, B, having its marked end downwards; then grasping the tongs, T, with the right hand a little below their middle, and keeping them nearly in a vertical line, let the bar, B, be rubbed with the lower end, L, of the tongs, from the marked end of the bar to its upper end, about ten times on each side of it. By this means the bar, B, will receive as much Magnetism as will enable it to lift a small key at the marked end; and when suspended by its middle, or made to rest on a point, this end will turn to the *north*, and is called its *north* pole, the unmarked end being the *south* pole.

When four of the soft steel bars are thus rendered magnetic, the other two, *A C*, *B D*, Fig. 286, must be laid parallel to each other, at the distance of about one-fourth of an inch, having their dissimilar poles united by the smallest pieces of iron, *A B*, *C*, *D*. Two of the magnetized bars are then to be placed together, as at *G*, with their similar poles united, and when separated by a piece of wood, at *I*,

they are slid four or five times backwards and forwards along the whole length of the bar, *A C*, so that the marked end, *F*, of *G* is nearest the unmarked end of *A C*, and *vice versa*.

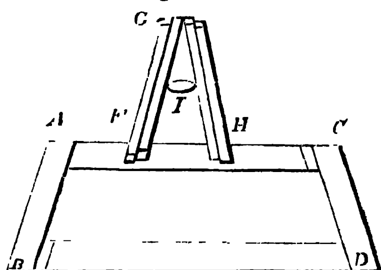


Fig. 286.

This operation is carefully repeated on *B D*, and on the other sides of both *A C* and *B D*. When this is done, the bars *A C* and *D* are to be taken up and substituted for the two outer bars of the bundles *G K*; these last being laid down in the place of the former, and magnetized in a similar manner. This operation must be repeated, till each pair of the soft bars has been magnetized three or four times.

When the six soft bars are thus magnetized, they must be formed into two bundles of three each, with their similar poles together, and must be used to magnetize two of the *hard* bars in the manner already described; and when they are magnetized, other two of the hard bars must be touched in a similar manner. The soft bars are now to be laid aside, and the remaining two *hard* bars magnetized by the *four* hard bars already rendered magnetic; and when this is done, the operation should be repeated by interchanging the hard bars, till they are impregnated with the greatest degree of permanent Magnetism which this method is capable of communicating to them.

(818) In performing the above operations, which may be completed in about half an hour, the bars *A C*, *B D*, and the pieces *A B*, *C D*, should be placed in grooves or fixed between pins of wood or brass, to keep them steady during the successive frictions which are applied to them. According to Canton, each of the six artificial magnets thus made, will lift about twenty-eight ounces troy. They should be kept in a wooden box, and placed so that no two poles of the same name may be together,—the pieces of iron being placed beside them.

(819) The method of "double touch," introduced by Michell and Duhamel, was much improved by Epinus, who substituted magnetic bars for the pieces of soft iron *M m*, forming the rectangle (Fig. 283). He then inclined the bundles of magnetic bars which formed his battery, and separating their dissimilar poles by a piece of wood, he passed them backwards along the whole length first of one of the steel bars, and then of the other, taking care to reverse the poles when passing from one bar to the other; the process was then repeated on the other sides of the bars. Epinus found that a maximum

effect was produced when the magnetizing bars were inclined 20° or 30° to the steel bars over which they passed.

Scoresby modifies this process by passing a horse-shoe magnetic battery round the whole parallelogram of steel bars in the same direction, terminating at the middle of one of the bars, instead of limiting the manipulations to the extent of the steel bars separately from end to end. For a pair of bars, tempered from end to end, 2 feet in length, 1·5 inch broad, and 0·6 inch thick, two circuits only of the parallelogram on each side of the bars by the large magnets were necessary, and in order to avoid hitching, and to make the magnet pass smoothly, the surfaces of the bars should be slightly oiled. By this modification of Epinus, Scoresby states that he was enabled to obtain one-seventh the additional power in two heavy bars.

(820) The following is an account of Coulomb's method of making artificial magnets, which consists of the most efficacious parts of the preceding processes, improved and extended by long experience. The apparatus which he uses consists of *fixed* and *moving* bundles of magnets. Each of the fixed bundles consists of *ten* bars of steel, tempered at a cherry-red heat, their length being about 21 inches, their breadth $\frac{6}{10}$ths of an inch, and their thickness $\frac{1}{4}$th of an inch. Having rendered them as strongly magnetic as possible, with a natural or artificial magnet, he joined them with their similar poles together, and formed them into two beds of four bars each, these beds being separated by small rectangular parallelopipeds, *m n*, of soft iron, projecting beyond their extremities, as shown in Fig. 287. The *moving* bundles consist of four bars tempered at a cherry-red heat, each being about 16 inches long, $\frac{6}{10}$ths of an inch wide, and $\frac{2}{10}$ths of an inch thick. When these bars were magnetized in the same way as the other bars, he united two of them by their width, and two of them by their thickness, so that each bundle was $1\frac{2}{10}$th inch wide, and $\frac{4}{10}$ths thick. The bars being separated as before, by pieces of soft iron, Coulomb found that all kinds of steel, provided the quality was good, were capable of receiving the same degree of Magnetism. In order to magnetize a bar, he placed the large fixed *bundles*, M N, (Fig. 288) in the same straight line, and at a distance of a little less than the length of the bar to be magnetized; and this bar, B B, was placed as in the figure, so as to rest on the projecting pieces of iron, so that the contact took place only over a length of $\frac{1}{4}$th of an inch: the two moving bundles, A A′, having their dissimilar poles separated by a small piece of wood or copper, about $\frac{1}{4}$th of an inch wide, between them; and each being in-

Fig. 287.

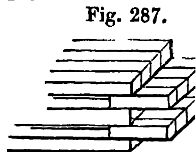
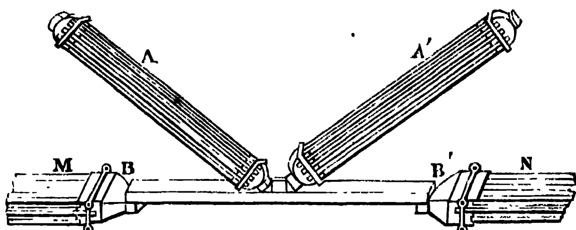


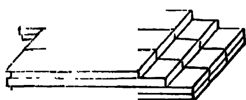
Fig. 288.



clined at an angle of 20° or 30° to the bar, B B'. The united poles of the moving bundles are then moved successively from the centre to each extremity of the bar, B B', so that the number of frictions upon each half of the bar may be equal. When the last friction has been given, the united poles are brought to the middle point of the bar, B B', and then withdrawn perpendicularly. The same operation is then repeated on the other side of the bar, B B'. If we wish to employ the method of Duhamel, we do not require the piece of wood or copper, but have only to separate the bars when the united poles are in the middle of the bar, B B', making each pole pass to the extremity of it.

(821) If the pieces composing the moveable magnets have not received their full power, they will, notwithstanding, communicate to the bars subjected to their action, a *greater* degree of Magnetism than they possess themselves. We may therefore now increase *their* power, by repeating the process on them with the bars which they have themselves impregnated: by so doing three or four times, we shall succeed in effecting their complete saturation. If the bars to be magnetized be very large, Coulomb recommends an increase of the number of the moveable magnets, each of the bars projecting beyond the last, as shown in Fig. 289. Thus the pole of each, which Coulomb supposes generally to reside at the very extremity of the bar, will come immediately in contact with the bar to be magnetized, when the compound magnet is applied to it with the proper inclination, and the whole will powerfully conspire to produce the same effect.

Fig. 289.



(822) *Horse-shoe Magnets.*—The form of a horse-shoe is generally given to magnetic bars when both poles are wanted to act together, which frequently happens in various experiments; such as for lifting weights by the force of magnetic attraction, and for magnetizing steel bars by the process of double touch, for which they are exceedingly convenient; fulfilling in this operation all the purposes of compound magnets.

(823) The following is the method of making a powerful magnetic battery of the horse-shoe form, recommended by Professor Barlow: "Take bars of steel, 12 inches long, and bend them into a horse-shoe shape, their length being 6 inches, their breadth 1 inch at the curved part, and $\frac{3}{4}$ths of an inch at their extremities, and their thickness $\frac{1}{4}$th of an inch. Let them be filed nicely, so as to correspond, and lie flatly upon each other. Then drill two holes in each, as shown in Fig. 290, and by means of screws, V V, passing through these holes, let *nine* horse-shoe bars be bound together. When the heads and ends of the screws are constructed so as to leave the outer surfaces smooth, the mass of bars must be filed as if they were one piece, and the surface made flat and smooth. When the bars are separated, let them be carefully hardened so as not to warp; and when they are cleaned and rendered bright, but not polished, magnetize them separately in the following manner: When the two extremities of the bar are connected by a piece of soft iron, M, the Magnetism may be developed in the two halves by Duhamel's method, as in Fig. 283; or, following Epinus, a strong magnet may be applied to each pole, and their extremities

Fig. 290.

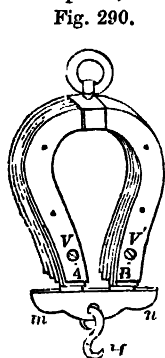


Fig. 291.

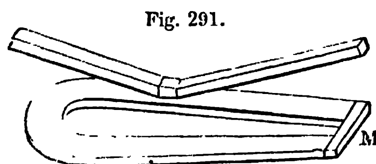
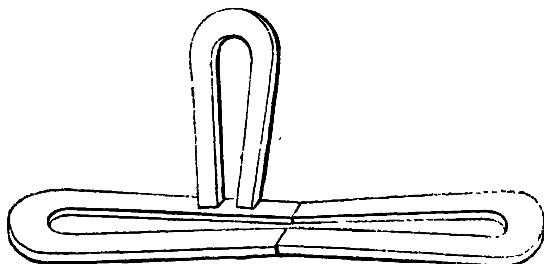


Fig. 292.



connected either with a piece of soft iron or another magnet, or two horse-shoe magnets may be applied to each other, as in Fig. 292, uniting the poles which are to be of contrary names. When the magnets are prepared in any of these ways, they are then to be magnetized with another horse-shoe magnet, by placing its north pole next to what is to be the south pole of one of the horse-shoe bars, and then carrying the moveable magnet round and round, but always in the same direction. In this way, a very high degree of magnetic

virtue may be communicated to each of the *nine* bars. When this is done, they are to be reunited by the three screws; and their poles or extremities connected by a piece of soft iron, or lifter, as in Fig. 34, having in its middle a hook, H, for suspending any weight. As the lifting power depends on the accurate contact of the poles of the magnet with the lifter, the extremities should, after hardening, be properly rubbed down with putty on a flat surface.

A magnet of this size and form was found by Professor Barlow to suspend *forty pounds;* but he afterwards found, that a greater proportional power could be obtained by using bars that were long in comparison with their breadth.

(824) The following is another simple and efficacious method of making artificial magnets, which has been successfully practised by Mr. Barlow. Having occasion for thirty-six magnets, 12 inches long, 1¼ inch broad, and $\frac{7}{16}$ths of an inch thick, he placed thirty-six bars of steel of these dimensions on a table, so as to form a square, having *nine* bars on each side, the marked or north pole of each bar being in contact with the unmarked or south pole. At the angular points of the square, the under edges of the bars were brought into contact, and the external opening thus left was filled up by a piece of iron 1¼ inch square, and $\frac{7}{16}$ths of an inch thick. The horse-shoe magnet described in the preceding section, was set upon one of the bars, so that its *north* pole was towards the unmarked end of the bar, and was then carried or rubbed along the four sides of the bars, and the operation was continued till the compound magnet had gone twelve times round the square. Without removing the magnet, each bar was turned one by one, so as to bring their lower sides uppermost, and the horse-shoe magnet was made to rub along the four sides of the square other twelve times. The bars were then highly magnetized, and the whole process did not occupy more than half an hour.

(825) This last process is the simplest, quickest, and most efficacious of all the methods that have been described; so that when a person is in possession of one good horse-shoe magnet, consisting of three or four bars joined together, he may afterwards make any number at the same time: indeed, the more the better. In removing the bars from each other after they have undergone the operation, it is advisable to place small pieces of soft iron on the poles of each before they are separated; for it is a fact well known to experimentalists, that a very considerable portion of the power of a bar is lost at the moment of its separation from others that have been impregnated with it; nor is it possible by any means to secure the whole of the Magnetism that has been given to it. By following the plan recom-

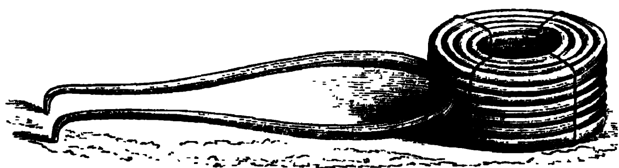
mended above, however, it will be found that a much larger portion is retained. The whole of the bars become in fact, as one single magnet; and the act of separation is, of course, analogous to that of fracture.

(826) Magnets should, when laid aside, be placed as nearly as possible in the position which they would assume in consequence of the action of terrestrial Magnetism. If this be neglected, in process of time they will become gradually weaker; and this deterioration is most accelerated when its poles have a position the *reverse* of the natural one. Under these circumstances indeed, unless the magnet be made of the hardest steel, it will eventually lose the whole of its magnetic power. Two magnets may also very much weaken each other, if they be kept, even for a short time, with their *similar* poles fronting each other. This will readily be understood from what has been said with regard to magnetic induction. The polarity of the weaker magnet is rapidly impaired, and sometimes actually reversed. All rough and violent treatment of a magnet should also be carefully avoided: every concussion or vibration amongst its particles tends to weaken its power.

(827) Horse-shoe magnets should have a short bar of soft iron, adapted to connect the two poles; and should never be laid by without such a piece of iron adhering to them. Bar magnets should be kept in pairs, with their poles turned in contrary directions, and the dissimilar poles on each side connected by a bar of soft iron, so that the whole may form a parallelogram. They should fit into a box when thus arranged, so as to guard against accidental concussion, and to preserve them from the dampness of the atmosphere. They should be polished, not with a view of increasing their Magnetism, but because they are then less liable to contract rust. Both single magnets and needles have their powers not only preserved but increased, by keeping them surrounded with a mass of dry filings of soft iron, each particle of which will react, by its induced Magnetism, upon the point of the magnet to which it adheres, and maintain in that point its primitive magnetic state.

(828) The following simple method of magnetizing steel bars was published by M. P. Elias, of Haarlem (*Phil. Mag.*, vol. 25, p. 348).

Fig. 293.



From 23 to 25 feet of well insulated copper wire are wound so as to form a hollow, very short, but very thick, cylinder. A current from a strong voltaic pair is passed through the wire, and the steel bar to be magnetized is placed in the cylinder in which it is moved up and down to the very ends. When the central portion of the steel bar again occupies the cylinder, the circuit is opened, and the bar, which is now perfectly magnetized, is withdrawn. When the bar is curved in the form of a horse-shoe, it is well to close it with its keeper during magnetizing; and when a straight one, to provide it at top and bottom with a piece of soft iron. The wire employed is $\frac{1}{8}$th of an inch in thickness. The voltaic apparatus is a single pair of Grove's (368), which has $\frac{1}{3}$rd of a square foot of active platinum. The resistance which the current meets with in this battery, is equal to that of a clean copper wire, $\frac{1}{26}$th of an inch in diameter, and 13 inches long. The hollow cylinder is 1 inch high; the bore nearly $1\frac{1}{2}$ inch in diameter, and the sides $1\frac{1}{2}$ inch thick. By means of this process, a steel horse-shoe bar, weighing 34 pounds, was magnetized to saturation by one single passage through a cylinder, constructed purposely for the experiment.

This mode of magnetizing is nothing more than the double passing of Duhamel or Michell, by means of galvanism; and far more powerful, easy, and certain. As in the double passing, the opposite poles of the magnet employed must be kept close together, so as to exert successively their greatest action upon each small part of the bar to be magnetized; in like manner the cylinder is made quite short, that each portion of the bar may experience the entire force of the voltaic element. Instead of a helix, Böttger (*Pogg. Ann.*, lxvii. 115) recommends a band-spiral of copper, which admits of obtaining the required amount of inductive power with the smallest amount of copper. By means of a spiral, weighing $4\frac{1}{2}$ lbs., 1 millimetre thick, and 20 broad, a 6-lbs. bar of very hard cast steel, when its poles were united with an armature of soft iron, was magnetized to saturation, as completely as it could have been by any known process of communicating permanent Magnetism, merely by passing the spiral once backwards and forwards along the bar. The same bar without the aid of the armature, even if the spiral were passed over it many times, did not assume more than 0·6 of this power. The celebrated Logeman magnets are made according to the method of Elias; their strength in proportion to the quantity of steel, is unusually great. Poggendorff describes a small horse-shoe magnet, weighing rather over a pound, which possessed a constant lifting power of $31\frac{1}{4}$ lbs.

(829) *Circumstances which affect the Energy of Artificial Magnets.*—

Quality of steel denomination (such as cast steel, shear steel, blister steel, &c.), temper or hardness, mass and form, are stated by Dr. Scoresby (*Brit. Assoc.*, *Cork*, 1843) to be among the principal. From the varying influence of these circumstances, it is impossible to give a general answer to the inquiry as to the best kind and temper of steel bars for permanent magnets. For large compound magnets, the best cast steel made as hard as possible, is the most effective; for small magnets and thin compass-needless, cast steel, tempered, is the best. The power of a magnet is essentially dependent on both quality and hardness. Scoresby has determined experimentally, that proportional magnets of similar steel and temper, are not energetic proportionally with their masses; in other words, that two magnets, one for instance, in all its dimensions being double that of the other, will not exhibit power corresponding with the masses, or in proportion to the cubes of their lengths; the proportions instead of being as $1^3 : 2^3 = 8$, would perhaps be found to be as 1 to 5 or 6 only. From this he infers that magnets cannot be advantageously enlarged to an indefinite extent. Scoresby also found that the same condition did not obtain with straight bars and with horse-shoes; that whereas with the former, in large combinations, extreme hardness is the most effective; in horse-shoes, the bars must be annealed at a temperature of about 505°, to give them their greatest lifting powers.

(830) *Directive Power of Magnetized Bars.*—For ascertaining this point, Coulomb employed his balance of torsion (56). Dr. Scoresby, however, recommends as sufficiently exact for practical purposes generally, the method of deviations. The bars to be examined and compared are laid in a horizontal position, and at right angles to the magnetic meridian, so as to be precisely in the plane of the magnetic equator of the earth, in order that they may receive no inductive influence whatever from terrestrial Magnetism, and thus exhibit only their own actual energy. A compass needle is suspended at a given distance, say five or six times the length of the compass needle, and the *tangents of deviation* produced by the different bars, provided they are of the same length, afford a satisfactory estimate of their proportional powers.

In order to ascertain the relative strength or tenaciousness of magnetic bars, compass needles, &c., Scoresby first ascertains their directive energy separately, and then binds them up into a bundle with their corresponding poles in contact; he then takes them apart, and again determines their directive energy. Sometimes the bars have their poles reversed by this treatment. In this way, surprising differences were detected in bars apparently similar. The following

is an example: 32 large uniform plates of cast steel, tempered throughout their length, of 2 feet long, 1½ inch broad, and ·042 inch thick, and weighing on an average 2,869 grains, were each magnetized to saturation by his modification of Knight's process. The mean power of deviation on a compass at one length distance as tried separately, was 16° 10′, the weakest bar causing a deviation of about 15°, and the strongest about 18° 30′. They were all then placed for a short interval in one fasciculus with their similar poles together, and before being entirely separated, the several plates were alternately changed as to positions, and transferred to different parts of the mass. The whole series being now separately examined again, the average deviating power was found to be reduced to 7° 35′, but the amount of deterioration suffered by the individual plates was singularly different, some retaining a deviating power of 10°, others retaining only from 2° to 4°, and some losing their power altogether. Yet these bars were constructed out of the same mass of steel, wrought by the same hand, and tempered precisely alike; and the manufacturer was probably not at all aware of the difference, nor could he by any decided or satisfactory means, separate the good from the bad.

(831) For testing the bars or needles of compasses of uniform, or nearly uniform dimensions, Scoresby employs a powerful, perfectly hard bar-magnet, of length and width corresponding pretty nearly with the dimensions of the plate to be tried. The test magnet he usually employs consists of a rectangular prism of best cast steel, thoroughly hardened throughout the mass, 6 inches in length, and ½ an inch square. Its power is great, occasioning a deviation of 38° to 39° on a compass at 12 inches, or two lengths distance. When employed for testing, its power is first reduced by laying it on a similar bar with corresponding poles coincident, which brings its deviating power down to about 33° or 34°. In this reduced state, the testing of any number of compass needles, or other small bars produces no further deterioration, so that the degree of violence to which each is subjected, may be considered as precisely similar. The bars to be tried after being thoroughly magnetized, are laid in succession upon the test bar, with similar poles in contact. The mere momentary contact of the two sides of the plate is sufficient, care being taken to bring the plate or bar evenly down upon the test magnet, without sliding or friction. The time required for the whole routine of this process, is only about a minute to a minute and a half for each bar; and the precision of the result is such, that the whole series, though amounting to several dozens, can be satisfactorily arranged in the order of their relative tenaciousness, or strength,

in a numerical succession. The bars best adapted for compasses, are those in which the product of the forces of the original power and the reduced power is greatest.

(832) *Ratio of Power to Mass.*—Captain Kater had deduced from his investigations on "the best kinds of steel, and form for a compass needle" that the directive force in needles of nearly the same length and form is as the mass. Scoresby's experiments do not confirm this, but they show on the contrary, that the ratio of augmentation of power diminishes as the thickness increases. The softer the metal, the less its tenacity, and he found an undeviating accession of power, or capacity with the increase of hardness.

(833) *Steel for Magnetical Instruments.*—It results from Dr. Scoresby's experiments that the system prevalently acted on in the construction of magnetical instruments generally, is grounded on an erroneous supposition, as to the capacity of steel of different degrees of hardness for the magnetic condition. It was imagined that a moderate hardening of the *ends* only of bars destined for magnets was necessary, but this mode of tempering possesses no advantage as to capacity, whilst it has much disadvantage as to tenaciousness, except in very thin bars. Thus, Scoresby could only give a very weak power to a large bar 8 feet long and 3 inches wide, made out of a flat bar of iron, steeled and tempered at the ends. A moderate hardening of the steel throughout was abundantly proved by Scoresby to be the most efficacious. As a general proposition also it is erroneous to suppose that perfectly hard steel bars, have an inferiority in capacity for the magnetic condition. It was found that in all masses above the weight of 130 grains, *perfectly hard steel* was superior in capacity to soft steel, in masses above 250 grains' weight, superior to bars tempered only at the ends, and above 400 grains, superior to any of the kinds of tempering with which it was compared. Scoresby, moreover, found no difficulty in magnetizing to any degree of energy *very hard bars*, even when of considerable thickness.

(834) *The Magnetic Test applicable to the Determination of the Quality of Steel Bars.*—Dr. Scoresby examined in the state as nearly as possible of raw material, both when soft, and when hardened at a white heat in salt water, bars of common spring steel, single shear steel, double shear, blister, and common cast steel, perfectly similar (as to weight and size), and the results revealed such a relation between the magnetical properties of the several bars, and the respective qualities of their denomination of steel, as to show that the magnetical properties may be rendered available not only for ascertaining the degrees of carbonization, but for the determination of the essential quality of the iron out of which it may have been manufactured. He

adds: "It is not perhaps unreasonable to expect, that were all the varieties of magnetic capacity in each denomination of steel, and in each quality as respects the iron out of which the steel is 'converted,' experimentally ascertained, a strictly scientific process of testing founded on these principles, might be devised—a process which might possibly exhibit results, if not as exact, at least as conclusive in certain most important relations of value in the metal, as are obtained by the beautiful process of assaying." Scoresby found a constant relation between the *ductility* of iron, and its magnetic capacity. The best iron possesses the highest magnetic quality, and therefore the best steel; the cast steel for example converted out of the best Swedish iron, such as that known technically, with reference to its mark, as "*hoop L*" would be expected to possess higher magnetic properties than the cast steel made out of iron of acknowledged inferiority of quality.

(835) *Construction of Magnetic Batteries.*—By combining the principle of the diffusion of energy by the combination of *separated* plates, with that of the selection by testing of powerful and tenacious plates, very powerful magnetic batteries may be constructed. When the plates were of a *spring* temper only, Scoresby found that a limit to the number that could usefully be combined was soon attained; but with hard plates, in which the power of sustaining violence was very great, he has constructed magnetic batteries of 15-inch plates, the power of which has gone on efficiently accumulating to the amount of 192, the power being five or six times as great as could possibly be obtained in any extent of combination whatever, in bars of similar length of the usual kind employed. He found it impossible, by the ordinary process, to communicate the full charge of magnetic influence to very hard shear steel, or cast steel bars, or such as were best suited for retaining it, and therefore best for the manufacture of compasses; but by interposing thin bars of soft iron between the charging poles of the magnet, and the steel to be magnetized, he could give a remarkably strong charge by a single stroke of the poles of the magnet over the bar.

(836) *Laws of Magnetic Combinations.*—The following general results of a long and laborious course of experiments, conducted by the same indefatigable magnetician, are of too high a practical value to be omitted. It was established:—

1°. That any *single* bar is proportionally more powerful than two or more corresponding and equal bars.

2°. That a *combination* of magnetic bars is always more powerful than any single bar of precisely the same steel of equal weight.

3°. That the *absolute gain* of power in the combined mass by each additional plate or bar *progressively diminishes.*

4°. That, beyond a certain extent, continued additions to a powerful combination of bars is not only not beneficial, but positively injurious.

5°. That a certain amount of deterioration in the permanent energy of all the bars in combination takes place by every addition of power to the mass.

6°. That the measure of tenacity or strength of a plate may be tested by its relative deterioration when combined.

7°. That though a weak plate may have its power totally destroyed in a large combination, it may be capable of considerable power and retentiveness of energy in a smaller combination.

8°. That besides a *permanent* deterioration of power, magnetic bars suffer by combination a certain amount of *transient* deterioration, which they recover on separation.

(837) *Separation of the Combined Bars by Limited Spaces.*—The following results were arrived at:—

1°. That the effect of combination is increased in proportion as the spaces between the plates are enlarged.

2°. That by thus preventing the plates from coming into contact, a larger number of plates may be advantageously combined.

3°. That in proportion as the density of the mass is thus diminished by separation, the amount of permanent deterioration in the several plates is also diminished.

4°. That when separated by discs or blocks, weaker plates can be combined advantageously to a much greater extent than when in contact.

5°. That an advantage is gained by a partial separation, such as that in the middle of the plates, but the effect is not so good as when the separation is complete.

(838) *Hardness and Temper.*—It was established:—

1°. That the relative powers of combinations of magnetized plates or bars of steel, as well as those of simple pieces, are greatly affected by differences in the state of the steel, both as to its quality and temper.

2°. That various degrees of hardness have an influence on the magnetic capacity and energy of steel, differing both in the nature and quality, in proportion to the magnitude of the masses employed; so that the kind of tempering which may exhibit superiority with a certain mass, may be greatly inferior in other magnitudes.

3°. That though with certain limited masses, partially tempered or slightly hardened bars have a pre-eminence, nevertheless, in fixity or permanence of power, the softer magnets are always inferior.

4°. That under certain conditions, and with small combinations,

an advantage is gained by heating the middle of thoroughly tempered plates, and so softening them.

5°. That for all practical uses, the limits of hardness may be considered as comprised between a brittle hardness like that of files, and that of an elastic or spring temper.

6°. That in sustaining power, hard bars have a superiority; and that for heavy bars, the greater the hardness the more powerful the magnet.

7°. That in the construction of magnetic batteries, the steel should be similar in quality throughout, and the bars as near the same size as possible.

(839) *Qualities of Steel.*—Dr Scoresby ascertained:—

1° That the magnetic capacity differs in each denomination of hard steel, being the lowest in those kinds susceptible of the greatest hardness.

2°. That in thin and medium plates made quite hard, *shear steel* possesses a higher capacity, and exhibits a greater energy in the individual plates, than blister or cast steel, and cast steel the least of all.

3°. That the comparative magnetic powers of different denominations of steel change their relation to each other *in combination;* each denomination under powerful combinations exhibiting a degree of effectiveness, according apparently, to its susceptibility for hardness.

4°. That *cast* steel being capable of the greatest hardness, is as a denomination, most effective in large straight-bar magnets, whether consisting of single massive plates, or of combinations of thin plates.

5°. The better the iron out of which the cast steel is made, the better the magnetic properties of the steel; the harder the steel also, the better for magnets of great energy, but for single thin plates cast steel from Bradford iron is the best.

(840) Hard *thin* plates gain in power by boiling in linseed oil, while medium or thick plates lose by a similar treatment. The tenaciousness of the magnetic condition is much impaired by annealing large thick straight bars or combinations, but the result is different with thin best cast steel bars.

(841) Although no universal answer can be given to the question—What is the best kind of steel, and the best kind of hardness, or mode of tempering for magnetical instruments? yet the following summary deduced by Scoresby, from his innumerable experiments, may prove very useful to the practical magnetician.

For all large or massive single and compound magnets of the straight-bar form, *the best cast steel* made quite hard; for horse-shoe

magnets, if single, cast steel annealed from file hardness at a temperature of about 550°, or *shear steel* a little reduced; and for compound horse-shoe magnets, cast steel annealed at 480° to 500°, or shear steel perfectly hard: for compass needles, if single and heavy, such as are suited for stormy weather, *hard cast steel;* if light or of moderate weight, whether single or compound, the best cast steel annealed at 500° or 550°, or hard shear steel, or hard cast steel from Bradford iron; and for very light needles or other small magnets the best cast steel annealed at the heat of boiling oil.

(842) *Measure of Permanency.*—The degree of retentiveness of magnets is directly as the hardness, and inversely as the energy. The loss of energy by time in unprotected magnets is much more considerable at first than subsequently. The retentiveness of combinations of thin bars is quite equal to that of single massive bars, especially if the plates be separated by a little distance; and soft magnets if properly protected, are as enduring as hard; and when the maximum power of a magnet is slightly reduced by unfavourable proximity to another magnet, the resulting energy is still less influenced by time.

(843) *Cast Iron Magnets.*—The magnetic capacity and retentiveness of cast iron, though considerable, is greatly inferior to that of properly hardened steel. The better the quality of the cast iron, and the more rapidly the casting is cooled, the more favourable the metal for Magnetism. Scoresby found that good cast iron was quite equal to *soft* steel for single plates, and much superior for large combinations. Hard thin bars of No. 1 pig metal are capable of forming powerful compound bar magnets, quite as strong as solid massive bars of ordinary steel, if only hardened slightly at the ends. Mr. Hearder constructed a compound cast iron horse-shoe magnet, which was capable of lifting 60 lbs., and the power was very permanent. It was composed of 24 bars of the best pig-iron, as hard as green sand could make them. The bars weighed 3 lbs. each, the weight of the combined series being about 70 lbs. The cost of this magnetic battery was not more than twelve or fourteen shillings, whereas a steel magnet of equal power would cost two or three pounds.

(844) *Useful Applications of the Magnetic Powers.*—Among these may be mentioned the magnetic steel masks, worn by the Sheffield needle-grinders to arrest the minute particles of steel which are constantly flying from the wheel, and which would otherwise enter their lungs. These masks are found, after the day's work, fringed with fine particles of steel—a proof of their protecting power. Magnets are also used in paper mills to abstract from the pulp the little particles of iron which arise from the abrasion of the machinery, and

which, under the form of peroxide, frequently disfigure the commoner kinds of paper. The attractive power of magnets is also employed for abstracting the filings of iron from among the dust of other metals of a more valuable character. An exceedingly ingenious application of the magnetic influence to the determination of the thickness of rocks was made by Dr. Scoresby. It is founded on the method of deviations (83), the direction of the needle obeying the same laws, whether the forces act in it merely through an interval of air, or through rock, iron, or other materials. We have seen (830) that the deviations of a small compass needle by the action of a magnet placed in the line of its centre at right angles to the meridian, may be taken as a measure of the force of the magnet; if, therefore, we determine beforehand the amount of deviations for different distances between the magnetic bar and the compass needle, we can apply the instruments to the determination of the thickness of any substance placed between them. The needle is placed on one side of the rock, and the magnetic bar perpendicular to its centre on the other, and the amount of deviation of the former is compared with the table of deviations deduced from the preliminary experiments. In this way Dr. Scoresby states that he can determine the thickness of 2 or 3 feet of rock to ¼th of an inch, and that he can measure distances of from 125 to 150 feet with great approximation to truth. He found that neither iron nor ironstone interfered with the results, for on placing the magnets and the needle one each side of a locomotive engine, the effect was not interfered with. The application of this method to mining operations, and especially to tunnelling, is likely to be very valuable.

(845) *Laws of Magnetic Force.*—This subject has occupied the attention of many of the most profound mathematicians. Newton inferred " from some rude observations" that the power of a magnet decreases not in the *duplicate* but almost in the *triplicate* ratio of the distance. Hawksbee's experiments (*Phil. Trans.* 1712, vol. xxvii.) gave a law of force which varies as the *sesquiduplicate* ratio of the distances, and his results were subsequently confirmed by Whiston and Taylor (*Phil. Trans.* 1721). Muschenbroek's researches, made a few years later, led him to the conclusion " that no assignable proportion exists between the forces and the distances, whether of attraction or repulsion." Mayer and Martin, who wrote on the subject between the years 1750 and 1760, both came to the conclusion that the true law of the magnetic force is identical with that of gravitation, and that in the previous experiments of Hawksbee and others, proper allowance had not been made for the disturbing changes in the magnetic forces so inseparable from the nature of the experi-

ments. Lambert's researches* (*Historie de l'Academie Royale des Sciences, Berlin*, 1776), which were described by Dr. Robinson as worthy of Newton himself, determined that the action of Magnetism on a magnetic needle, considered as a lever, is proportional to the lines of the angle of obliquity of its direction; and that hence the effective force which operates in restoring the needle to its meridian when drawn aside from it, is directly as the line of the angle of its deflection. The law of force was found to be the inverse duplicate ratio of the distances. The directive or polar force of a magnet upon a small needle, was shown by Lambert in a subsequent memoir to be "as the absolute force or magnetic intensity of the particles directly, and as the squares of the distances inversely." Lambert's deductions were confirmed twenty years later by Coulomb, by means of his torsion balance, and more recently (about the year 1817), by Professor Hansteen, of Christiania.

(846) Amongst the latest inquiries are those of Sir W. Snow Harris. (*Edinb. Phil. Trans.*, 1829; *and Rudimentary Magnetism*, Part III.) He first investigates the laws and operation of the elementary forces of induction—the essential function of all magnetic development. When a bar of soft iron and a magnetic bar are opposed to each other, the near pole of the latter induces on the near parts of the former, a polarity the reverse of its own, and a polarity of a similar nature on parts at a distance. The temporary polarity of the iron reacts on the magnet by a kind of reflection or reverberation, inducing on it a new temporary polarity of the same character as its own permanent one; this new force again reacts on the iron, and thus a series of magnetic waves is produced, each becoming weaker until they vanish into rest. Magnetic attractions and repulsions being the results of this inductive reverberation, the study of the laws of the elementary force of induction became necessary as a preliminary to the investigation of the laws of the magnetic force generally.

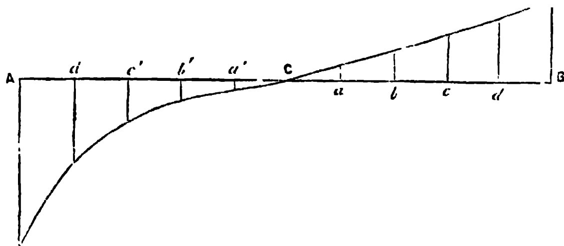
(847) The apparatus employed by Harris was his Hydrostatic Balance, which he found well adapted to the measurement of very small magnetic forces. It appears that there is a limit in respect of the elementary inductive forces, different for different magnets, and varying with the magnetic conditions of the experiment; but as a general rule, it was concluded, that the elementary force of magnetic induction is as the Magnetism directly, and from the $\frac{1}{2}$ or square root to the $\frac{3}{2}$ power, or sesquiduplicate ratio of the distance inversely. Applying these results to the explanation of the different laws of

* For a full discussion of these profound researches, the reader is referred to Sir Wm. Snow Harris's Rudimentary Magnetism, Part III.

force, deduced experimentally by Lambert, Coulomb, and others, Harris shows that their seeming contradictions and differences may be reconciled, and that the deduction of Brook Taylor, "that magnetic attraction as commonly observed, is quicker at greater distances than at small ones, and different for different magnets," is a necessary result of the elementary laws of Magnetism.

(848) *Law of Force in different Points of a Magnetic Bar.*—Harris also applied his Hydrostatic Magnetometer to the determination of this problem. The investigation had previously been made by Coulomb, by observing the vibrations of a delicately suspended magnetic needle when brought into various positions, in respect of a long magnetic wire, placed vertically in the magnetic meridian, the dissimilar polarities being opposed to each other. The force due to any given point of the magnetic wire was considered to be proportional to the square of the number of vibrations; the constant and previously determined force, by which the needle vibrated when away from the wire, being deducted. In this way Coulomb obtained as a curve of intensity, a logarithmic curve, the ordinates of which *a b c*, &c., are in geometrical progression, while the abscissæ C *a*, C *b*,

Fig. 294.

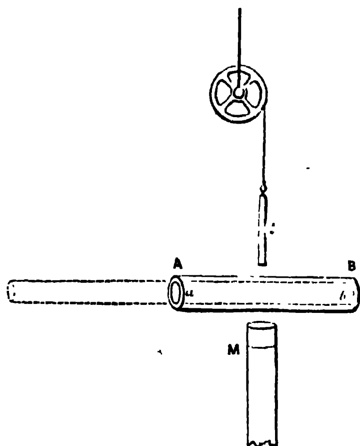


&c., corresponding to these ordinates, are in arithmetical progression, From the many difficulties attending this method of examination, and from the irregular distribution of the Magnetism in the bar, arising from the imperfection of its temper, &c., it is to be doubted whether the true law of intensity is really represented by this peculiar curve. Harris examined the forces at successive points of an accurately divided, powerfully magnetized, and equably tempered bar through a small cylindrical armature of soft iron; the square root of the forces taken in degrees on the graduated arc of the balance being considered to represent very nearly the comparative magnetic development. His results showed that the Magnetism in different parts of a regularly tempered and magnetized steel bar of uniform texture is directly as the distance from the magnetic centre,

whilst the reciprocal force between any given point and soft iron, is as the square of the distance from that centre.

(849) *Law of Magnetic Charge.*—The amount of Magnetism in a bar of well tempered steel, under a given attractive force, is independent of the mass of the magnetized body. This, Harris proved by a very beautiful experiment. He placed between the magnet M, Fig 295, and the trial rod, *t*, of his magnetometer a small cylinder of soft iron, A B, into which could be inserted as a core, a closely fitting solid cylinder, *a b*, also of iron. The magnet was placed at a constant distance below the cylinder, and the attractive forces on the trial rod were measured when the interposed cylinder was hollow, when its core was in its place, and when it was drawn out (as represented by the dotted lines in the figures), so far as to double the extent of the interposed surface; when the joint cylinders were taken together as a mass, and when the interior cylinder was altogether removed, the force was in both cases the same, amounting to 10°, but when the core was drawn out so as to extend the surface to the greatest limit, the intensity fell to 5°, being diminished one-half. Hence Magnetism, like Electricity, is only influenced by surface, and a hollow steel cylinder may be made to acquire as much magnetic power as a solid cylinder of the same dimensions.

Fig 295.



(850) In order to determine experimentally the intensity of Magnetism in respect to the quantity developed, and the extent of surface over which it is dispersed, Harris surrounded a soft iron bar with three distinct and similar coils of wire, which could be connected with three distinct and similar voltaic batteries; he then examined the attractive forces on the trial cylinder of the magnetometer, when the iron rod was magnetically excited by one, two, and three of the coils; the batteries being precisely similar, were assumed to develope each when taken singly, the same amount of magnetic force, and it was found on trial that the intensity was very nearly as the *square of the quantity* of Magnetism, being precisely the same law as that deduced for electrical charge, and therefore to obtain the relative quantity of Magnetism in operation we must take the square roots

of the respective intensities, the magnetic surface and all other things being the same. We have no experiments to show whether this law holds good with dissimilar magnetic bodies of variable size and surface, though it is probable that the law of surface is the same with that of Electricity, and that the intensity is as the square of the surface inversely, *i e.*, that the same quantity of Magnetism developed upon a doubled surface would have only ¼th the intensity.

(851) The latest experimental investigation of the laws of Magnetism is that of Tyndal (*Phil. Mag.*, N. S. vol. i. p. 295). The subjects of his inquiry were:—

1st. To determine the general relation between the strength of a magnet, and the mutual attraction of the magnet and a mass of soft iron when both are in contact.

2nd. To determine the same relation, when the magnet and the mass of soft iron are separated by a fixed distance.

3rd. A constant force being applied to the mass of soft iron, in a direction opposed to the pull of the magnet, to determine the conditions of equilibrium between this force and Magnetism, when the distance between the magnet and the mass varies.

4th. To determine the general relation between force and distance, *i. e.*, the law according to which the magnetic attraction decreases when the distance is increased.

(852) The following are the principal results:—

1st. The mutual attraction of a magnet and a sphere of soft iron, when both are in contact, is directly proportional to the strength of the magnet.

2nd. The mutual attraction of a magnet and a sphere of soft iron, when both are separated by a small fixed distance, is directly proportional to the *square* of the strength of the magnet.

3rd. The mutual attraction of a magnet of constant strength, and a sphere of soft iron, is *inversely* proportional to the distance between the magnet and the sphere.

4th. When the distance between the magnet and the sphere varies, and a constant force opposed to the pull of the magnet is applied to the latter, to hold this force in equilibrium, the strength of the magnet must vary as the *square root* of the distance.

CHAPTER XVI.

MAGNETISM—Continued.

Terrestrial Magnetism—Magnetical instruments—The land compass—The mariner's compass—The Admiralty compass—Harris's compass—Local attraction in ships—Scoresby's investigations—The dipping needle—The variation compass—The declination magnet—The horizontal force galvanometer—The vertical force galvanometer.

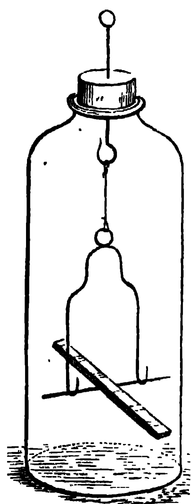
(853) The tendency of the magnetized needle or bar to turn *nearly* to the north and south, when left at liberty to move freely on a pivot, or otherwise suspended so as to allow of freedom of motion in a horizontal plane, is derived from a force supposed to reside naturally in the earth. The earth in fact must be regarded as a magnetic mass, operating on the magnetic needle, precisely in the same way as one magnet operates upon another.* If we communicate Magnetism to a steel bar which in its previous condition had been exactly equipoised when suspended freely from its centre, we shall find that it no longer maintains its horizontal position, but assumes an oblique one, being inclined with its north pole downward at an angle of about 69°. If we take this needle to different parts of the earth, we shall find its inclination to be different in different parts, the angle becoming greater and greater as we approach the poles, and less and less as we approach the equatorial regions.

(854) The following simple method of constructing a magnetic direction needle is given by Dr. Scoresby (*Magnetical Investigations*, vol. ii.) Two pieces of watch spring, each 2 inches in length, are slightly heated in the candle, and then coated on the concave side with the wax of a common taper; the waxed surfaces are then placed

* The total magnetic power, or "moment of Magnetism" of the earth, as compared with that of a saturated steel bar, 1 pound in weight, is calculated by Gauss to be as 8,464,000,000,000,000,000,000 to 1, which, supposing the magnetic force uniformly distributed, will be found to amount to about 6 such bars to every cubic yard.

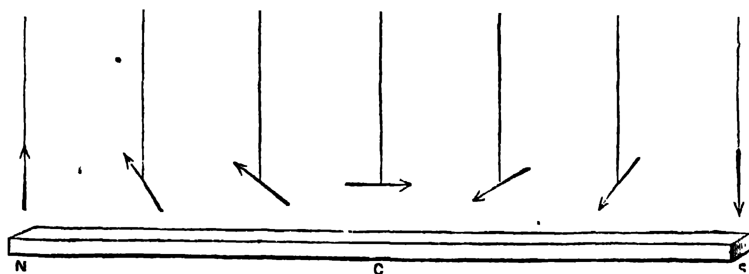
together, and the two pieces bound closely together by thread. A fine sewing needle is introduced as an axis between the two plates midway from each extremity. A piece of brass wire of the thicker size employed for the pianoforte, is bent into the form of a staple, the ends being turned up to receive the axis of the bar. The watch-spring needle is adjusted by a minute quantity of sealing-wax, and the centre of gravity adapted to the axis by accurately straightening the plates with the fingers; on magnetizing the needles, and suspending them by a silk fibre in a large jar, it acts beautifully as an inclination or dipping needle; any deviation from torsion of the silk may be detected by comparing it with a horizontal needle placed at a little distance, and may be avoided by suspending a weight equivalent to that of the needle from the fibre previous to using it.

Fig. 296.



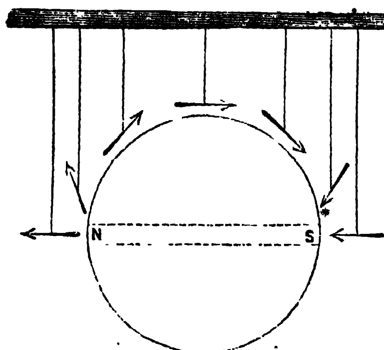
(855) The analogy of the earth to a magnet is beautifully illustrated, by holding a light and sensitive magnetic needle over different parts of a magnetic bar, laid horizontally on a table. The bar should be about 30 inches long, and powerfully and equally magnetized; the needle will assume the various positions indicated in Fig. 297.

Fig. 297.



Thus in the magnetic equator of the bar C it will be exactly horizontal; at N and S it will hang vertically, the N pole downwards at S and the S pole downwards at N, between the poles and the equator; the needle will take up different positions as it is moved along, becoming less and less oblique as it passes from the former to the latter, precisely as it would do if carried from the polar to the

Fig 298.



equatorial regions of the earth; or a bar magnet may be enclosed in a light wooden or pasteboard sphere, as shown in Fig. 298, and on passing a short dipping needle over the exterior surface of the globe, from pole to pole, the magnetic conditions of our planet may be still more strikingly illustrated.

(856) We have seen that when a piece of soft iron is brought into the neighbourhood of a magnet, it acquires by induction temporary magnetic properties; now it has long been known that rods of iron that have been kept for a long time in a fixed position acquire magnetical polarity: this property they have derived from terrestrial magnetic induction. The position most favourable for developing Magnetism in an iron rod, is that of the dipping needle, and accordingly we find that old kitchen pokers that have been standing for many years nearly in that position have become feeble magnets, their lower ends being N. poles; any piece of soft iron however, when held in the position of the dipping needle, is *pro tempore* a magnet. The following experiments of Scoresby are instructive on this point (*Magn. Invest.* vol. i.). Lay a compass very near the edge of a square table on the E. or W. side of it, so that the direction of the needle is parallel to the proximate side of the table; adjust the compass with its needle and N. and S. line in correspondence, and holding the kitchen poker horizontally in the direction of the E. and W. points of the compass, strike it a blow or two with a hammer to neutralize any Magnetism it may have; the poker whilst held in a vertical position being now brought within 3 or 4 inches of the compass E. or W. of its centre, will strongly *attract* the N. pole when the *upper end* is on a level with the compass, and *repel* the same pole when the lower end is raised to the same level, indicating a *southern* polarity in the upper, and a *northern* in the lower. The evanescent character of this induced Magnetism is further shown by placing the knob end of the poker held horizontally, against the edge of the table, with the compass about 3 inches within; raising the point with one hand, whilst the knob is kept steady against the table with the other (like a ball moving in a socket); the N. pole of the needle will gradually recede till the poker becomes vertical, and then lowering

the point, the N. pole will gradually approach the knob till the poker becomes again vertical, in the direction opposite to its former position; thus showing that the knob had obtained northern polarity, when the bar was vertical with the knob *downward*, and southern polarity with the knob *upward*. By alternately raising and depressing the point of the poker, the needle may be kept in oscillation, and even in unceasing rotation if the movements are consistently continued. The point of the poker being down, and the rod in a vertical position, the quantity of magnetic action on the needle diminishes as the poker is brought to a horizontal position; if the poker be moved in an E. or W. plane, the action on the needle is *nil* when it is horizontal; but if it is moved in a N. or S. plane, and traversed northward of the compass, it will pass beyond the horizontal about 20° before the same neutral effect takes place.

The kitchen poker should be used in these experiments, as the parlour poker with a view to polish and firmness is usually steeled. The influence by which the Magnetism of iron bodies is thus spontaneously elicited, acts in a direction, not like gravitation, perpendicular to the earth's surface, but in a direction inclined in the same degree as that of the earth's magnetic action, and the plane of no attraction is at right angles to the line of the dipping needle.

(857) Soft iron may even be made to acquire temporary lifting power under the influence of terrestrial magnetic induction; thus Scoresby found that a piece of annealed iron plate, 15 inches long and 1·5 inch broad, with a smooth and polished end, when held in the position of the dipping needle could support an iron nail weighing 3 grains, and a thicker rod weighing 3,830 grains supported a nail weighing 10 grains; by combining a dozen such plates some further capabilities were elicited, but by no means corresponding with the increase of mass. By bending a piece of annealed iron plate 15 inches long and ¼-inch wide, reversely at the end, in the form of an architectural ogee, and suspending it by silk fibres, a meridional iron needle was made, that assumed true magnetic direction (though quite free from Magnetism), and was found, moreover, to obey extraneous influences precisely like a steel magnetic needle.

(858) Dr. Scoresby gives ("Magnetical Investigations," vol. iii.) the following general results of a very extensive investigation into the phenomena of terrestrial induction.

1°. That true Magnetism is induced in soft iron by terrestrial induction.

2°. That in masses of uniform temper and quality, the neutral plane is parallel with a plane at right angles to the dip, and obliquely through, or near to, the centre of gravity.

3°. That in spherical and other formed bulky masses, the magnetic axis coincides with that of the earth, the chief energy being at the extremities of such magnetic axis, and the neutral plane at right angles to the axis in the middle; but in bars and other elongated forms, the direction of the magnetic forces follows the course of the longitudinal extent of the bars, exhibiting the two polarities in maximum degree, at the opposite ends of the bar, with a neutral plane in the middle.

4°. That different kinds of iron, steel, and iron ores, differ in their respective capacities for terrestrial Magnetism; and that the capacity of each is influenced by its temper, hardness, and mass.

5°. That fasciculæ of thin plates have developed in them a somewhat higher power than solid masses of like dimensions, but that a progressive diminution of power attends the combination of plates—this being more marked in pure annealed iron than in cast steel.

6°. The magnetic energy of a mass of iron under terrestrial induction, is the resultant of two antagonistic forces—the developing force of the earth, and the tendency of the molecular Magnetism of the metal to a state of neutrality; hence bulky masses of iron receive inferior polarity to elongated masses of equal weight, and hollow shells and solid shots have equal magnetic development; this, however, is only true in certain special cases, when similar qualities of metal are compared.

7°. That the Magnetism terrestrially induced, becomes like that in permanent magnets, so highly concentrated at the extremities of elongated bars or plates of malleable iron, as to yield an attractive power sufficient to lift small portions of iron like a feeble magnet, and a directive power adequate to correct adjustment of position, in a plate duly suspended like the needle of a compass.

(859) The effects of percussion and of flexure in communicating Magnetism to soft iron bars while held in a vertical position, is very remarkable, and well worth stating, from its bearing on the important subject of the Magnetism of iron ships. A kitchen poker carefully deprived of Magnetism, by giving it a few smart blows while held *horizontally* E. and W., affected the compass needle at a given distance, when held *vertically*, point upwards, 21°; in the position of the dip, 22°. A smart blow with the hammer on the square side of the lower end, increased the *upright* deflecting power of the knob from 21° to 35°; six blows increased it to 44°, and gave it when in a *horizontal* position a deflecting power of 26°. On inverting the poker, a single blow not only neutralized its previous Magnetism, but changed the poles to an extent of 19° of deviating power; and six more blows gave it a *horizontal* deflecting power of 27°. The poker now being held horizontally *east* and *west*, a single blow

reduced its power to 3°. The effects were increased when the poker was hammered while held in the position of the dip.

(860) The following experiments are instructive as illustrating the effect of percussion and flexure:—

1°. Lay a small delicate compass needle on a table about 3 inches from the E. or W. side, the needle being adjusted to zero. Hold an iron poker (kitchen) point *upwards*, and strike it several smart blows on the top with a hammer; now turn it point *downwards*, and bring the knob against the edge of the table near the compass—little or no action will take place, because although a little northern polarity will have been communicated to the knob by the percussions, still the position in which the poker is now held will tend to produce in the knob a southern polarity by terrestrial induction, and the one will neutralize the other. Should, however, the N. pole of the compass be attracted, a few more blows with the hammer on the point (point upwards) will destroy this attraction. Whilst now the knob of the poker is on a level with the compass (point downwards), let a smart blow be struck on the top, the needle will start aside or whirl round the N. end, being attracted by the poker as if acted upon by some magical power.

2°. Provide two or three plates of thin sheet iron, about 18 inches long, 2 broad, and the thickness of a shilling. After having annealed them by heating them to redness, and allowing them to cool gradually, tie them flat in a bundle in brown paper, one end being marked. Destroy all Magnetism by moderate flexure without permanent bending, the handle being held horizontally E. and W. till there is no action on the needle. Hold the plates vertically, marked end *downward*, and give them a moderate flexure both ways, the marked end will now repel the *north* pole of the needle, probably 25° or 30°. Now bend the plates with the marked end *upwards*, and the polarity will be reversed. Next hold the plates E. and W., and bend them backwards and forwards; the polarity will, in all probability, be wholly, or nearly wholly destroyed.

Scouring, filing, polishing, or any other process acting on the surface of a piece of iron or soft steel, has a corresponding magnetizing or demagnetizing tendency with reference to the position of the metal when thus operated on.

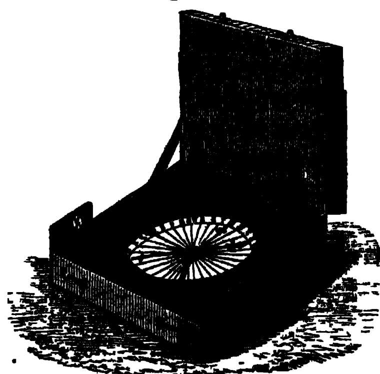
(861) On this principle, iron rods may be completely deprived of Magnetism. We have only to strike them a few blows while held in a horizontal position E. and W., testing them from time to time with a compass. For demagnetizing thin plates of iron which might become bent by hammering, the application of *flexure* is quite as effective and much readier. Scoresby magnetized an unannealed piece of iron

plate, 18 inches long, 1 inch broad, and ·1912 inch thick, as highly as possible, and found that six smart blows with a hammer, while the plate was in an upright position, N. pole upwards, were sufficient to disperse the Magnetism.

(862) When *steel* bars are hammered while held vertically or in the position of the dip, they acquire *permanent* Magnetism, but the magnetic lifting power is increased 30 to 1 when they are hammered while resting on the top of an iron bar also held vertically. Powerful magnets may thus be formed. Thus, Scoresby took 6 bars of soft steel, and having magnetized them by percussion, 2 of them connected at their extremities by two short pieces of soft iron, in the form of a parallelogram, were rubbed with the other 4 bars after Canton's method (816), by which their original power was greatly increased. These being substituted for two of the bars of the operating set, were applied with increasing efficacy to the new parallelogram; and the latter, after being thus strengthened, became effectively available for the improvement of the third pair of the series. After treating each pair of bars in regular succession, and through several repetitions of the process, the whole of the bars were found to be in a very high degree magnetical, apparently to the extent of their capacity, each pair readily lifting a weight of above 8 ounces.

(863) *The Land Compass.*—The needle is placed upon a point in the centre of a brass or wooden box, furnished with a graduated limb, and sometimes the ends of the needle are made to carry a vernier scale in order to bring down the readings to a minute or lower. The box which may be square, round, or octangular, is furnished with two straight edges of brass, or index marks to set to any proposed line, and sometimes with sights, the top being covered with glass to prevent the needle from being disturbed by the action of the air. There are also two small pieces of brass, one of them turning on a fixed point, seen in the figure, which is used to check the oscillation of the needle, by pressing upon the upper end; the ring at the other end of the lever is raised till it touches the needle which is thereby rendered steady; the lever is then let down, and the needle left to find its proper direction. In the figure the needle is mounted with a card

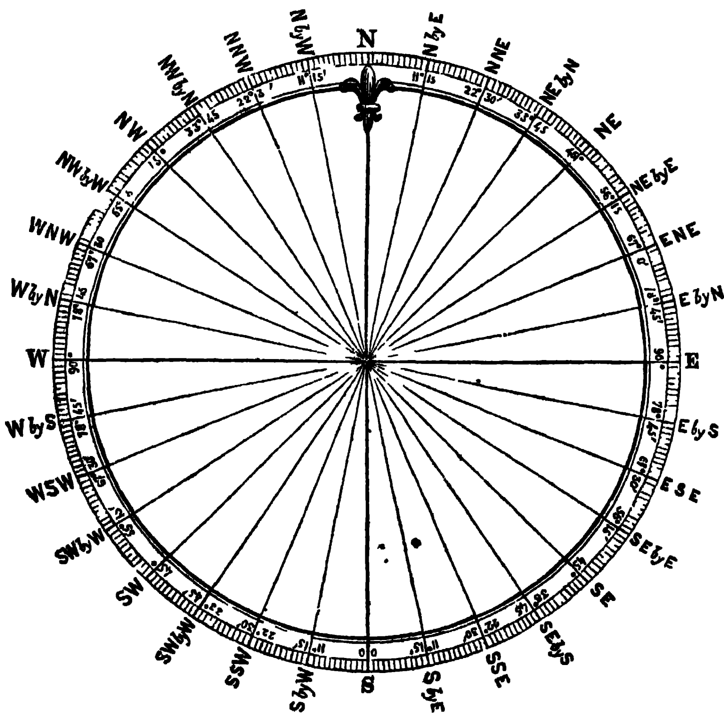
Fig. 298.



divided into points and quarter-points of the compass; the N. and S. points being made to correspond very exactly with the needle; in this form the general direction of an object will be known by observing its bearing, which will always arrange itself according to the magnetic meridian of the place of observation.

(864) *The Mariner's Compass.*—In its ordinary form it consists of a magnetic needle attached to a circular card, the surface of which is divided into the four cardinal points N., S., E., W.; these again are subdivided into 32 points which are called in nautical language *Rhombs*, from the Greek word ῥεμβω, to turn. In the azimuth compass the circle is divided into 360° parts. The position of the needle is usually estimated in terms of the 32 points, but for refined purposes it is found better to estimate the angular deviation of the needle from the line of the magnetic meridian, in degrees and minutes taken in reference to either the N. or S. pole of the card Thus instead of the Rhomb S. W., we say S. 45° W.; instead of E.N.E, we say N. 67° 30′ E., and so on. The card (Fig. 299) is balanced

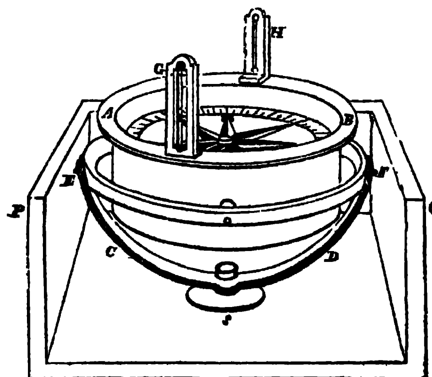
Fig. 299.



upon a pivot fixed in the bottom of a circular box, and the top of the box is a plate of glass for protecting the needle from the motion of

the air. In Fig. 300, A B is the compass box, suspended within a larger box P Q, upon two concentric brass circles or *gimbals*, the outer circles being both fixed by horizontal pivots to the inner circle which carries the compass box; the two axes upon which the gimbals move being at right angles to each other. The effect of this construction is that the compass box AB, will retain a horizontal position during the motions of the vessel. The instrument shown in the figure, is the Azimuth Compass; it is furnished with sights, GH, through which any object may be seen, and its angle with the magnetic meridian increased. For this purpose, the whole box is hung in detached gimbals, CD, EF, which turn upon a stout vertical pin, seen above S. In this compass the card is divided on its rim into 360°, but the divisions are more frequently placed on a light metallic rim which it carries. The eye is applied to the sight H, which is a slip of brass, containing a narrow slit. The other sight G, which is turned towards the object, contains an oblong aperture, along the axis of which is stretched a fine wire, which is made to pass over the object whose angular distance, or *azimuth*, from the magnetic meridian is to be determined.

Fig. 300.



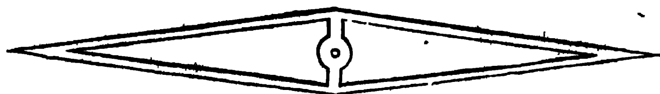
(865) The questions—Which is the best form, and What the best construction of compass needles, have been frequently discussed, and many valuable experiments have been made on the subject; the most important perhaps are those of Captain Kater and Dr. Scoresby.

The principal inferences to be drawn from the experiments of the former are the following (*Phil. Trans.*, 1821.)

1°. That the best material for compass needles is clock spring, but care must be taken in forming the needle, to expose it as seldom as possible to heat, otherwise its capability of receiving Magnetism will be much diminished.

2°. That the best form for a compass needle is a pierced Rhombus

Fig. 301.



in the proportion of about 5 inches in length to 2 inches in width, this form being susceptible of the greatest directive force.

3°. That the best mode of tempering a compass needle is first to harden it at a red heat, and then to soften it from the middle to about 1 inch from each end, by exposing it to a heat sufficient to cause the blue colour which arises again to disappear.

4°. That in the same plate of steel of the size of a few square inches only, portions are found varying considerably in their capability of receiving Magnetism, though not apparently differing in any other respect.

5°. That polishing a needle has no effect on its Magnetism.

6°. That the best mode of communicating Magnetism to the needle appears to be by placing it in the magnetic meridian, joining the opposite poles of a pair of bar magnets (the magnets being in the same line), and laying the magnets so joined flat upon the needle with their poles upon its centre; then having elevated the distant extremities of the magnets, so that they may form an angle of about 2° or 3° with the needle, they are to be drawn from the centre of the needle to its extremities, carefully preserving the same inclination, and having joined the poles of the magnets at a distance from the needle, the operation is to be performed 10 or 12 times on each surface.

7°. That in needles of from 5 to 8 inches in length, their weights being equal, the directive forces are nearly as the lengths.

8°. That the directive force does not depend upon the extent of surface, but in needles of nearly the same length and form, is as the mass.

9°. That the deviation of a compass needle occasioned by the attraction of soft iron, depends, as Mr. Barlow has advanced, on extent of surface, and is wholly independent of the mass, except a certain thickness, of the iron amounting to about $\frac{3}{10}$ths of an inch, which is requisite for the complete development of the attractive energy.

(866) The pierced Rhombus was the form of needle used in merchant ships previous to the researches of Dr. Gowan Knight in 1750. This form he considered objectionable, as likewise the needle employed at that time in the Navy, which was a single piece of spring tempered steel, broad towards the ends, which were pointed, and tapering towards the middle; and he proposed as the most advantageous form, that of a regular parallelopiped, or straight narrow-edged bar, hardened throughout and suspended upon an agate attached to its under surface, and this kind of needle is now usually employed.

(867) The general results of Dr. Scoresby's experiments on the magnetical capacities and powers of steel plates adapted for sea compasses, have already been given. The following is a more complete resumé of his investigations.

1°. For single bar needles exceeding in weight 400 to 500 grains, the 6-inch bar, *hard* cast steel; for lighter needles, the directive energy is improved by annealing.

2°. The most energetic *cast* steel is that from Bradford iron; next comes *shear* steel SS, or of *hoop* L iron; then *blister* steel *hoop* L; and lastly *cast* steel *hoop* L.

3°. *Thin* plates of cast steel for single needles have their magnetical capacities improved by annealing in oil, at a temperature of from 500° to 550°.

4°. A great advantage is gained by employing two or more thin plates not in contact, but separated from each other; the plates being either of hard shear steel, or of slightly annealed cast steel.

(868) The compass recommended by the Committee of Inquiry appointed by the Admiralty is constructed in accordance with Scoresby's principles. It consists of 4 compound magnetic bars secured together with a card within a light ring of brass: the card is made of mica, and covered with thin paper, on which the impression of the cardinal points is printed; the caps are of agate or ruby, and the points of suspension of native alloy; the bowl is made of copper. It is a beautifully constructed instrument, but costly, and is said to be not very steady at sea.

(869) Sir William Harris's compass, which is also used in the Navy and by the Honourable East India Company, is thus constructed by the patentees, Messrs Lilley and Son, Opticians, Limehouse. The needle is a simple light bar magnet, from 5 to 7 inches in length, turned on its edge, and mounted on an agate centre. It is regularly and accurately formed, hardened and tempered throughout, and previous to being magnetized is nicely balanced in a horizontal position; in this state two small silver sliders are placed on each arm equally distant from the extremities and centre of the bar. When the bar is made magnetic, it is magnetized in such a way, that the centre of the magnetic forces falls in the line of the point of suspension, and any inclination in the direction of the dip is corrected by moving one of the sliders a little towards the centre on one arm, and a little from the centre on the other arm. By this new distribution of the matter, the bar is again brought into a horizontal position, and all undue tendency to an oscillating or swinging motion so far avoided, for there is still as much matter to be moved on one arm of the lever as on the other, whilst the change of the angular inertia of the sliders is so small that

it may, for all practical purposes, be neglected in the calculation. The needle, though light, has considerable magnetic power, lifting at either pole three times its own weight of iron, and producing according to Scoresby's method of deflections, a deviation of 22° at a distance of twice its length from the centre of the trial needle.

The needle and card are placed closely within a dense ring of pure copper, the influence of which, as has been already shown (785) is to bring the needle rapidly to rest in its meridian, whenever from any cause it is put into a state of oscillation; so that the effect of disturbing forces on the card (a very light disc of talc), such as that of a ship's motion at sea, is checked at the instant without the aid of mechanical restraint,* and the needle is thus prevented from moving out of its natural position, at least to any inconvenient extent, by means of an invisible agency, and without any interference with its directive property. This effect of the copper ring in calming the oscillations of the compass, may be immediately seen by attracting the needle aside 90° from its meridian, with a small piece of iron, and allowing it to swing from that point, when it will be observed to be rapidly reduced to rest at each swing. Thus in an experiment described by Messrs. Lilley, a needle and card of 7 or 6 inches in diameter, were observed in an open space to make 25 swings and to occupy 200 seconds, in coming to rest from an angle of 90°, whereas within a ring of copper, it came to rest in 5 swings and only occupied 40 seconds. The needle point is centrally fixed in a transverse bar placed as a diameter to the ring of copper. Should the point wear, or be damaged from any cause, it may be unscrewed and screwed in the reverse way, the point being a double one. The cap also can be renewed when requisite. The compass kettle is fitted with faces of plate glass, so that the card may be lighted from below or above it. These compasses can be fitted to any binnacles, and adapted to any locality of situation on board. When the horizontal position of the card is disturbed by any alteration of dip incidental to a change of latitude, it is to be corrected by moving the silver sliders on the needle.

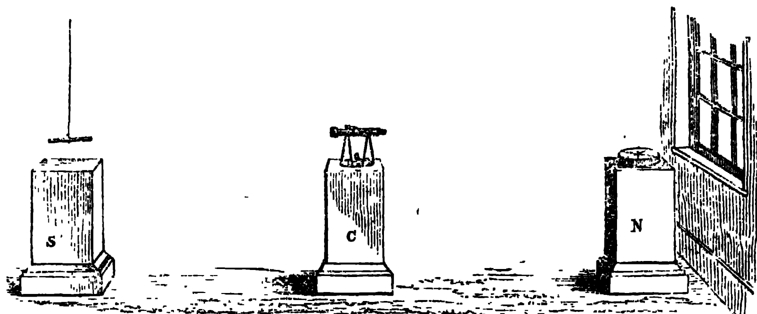
(870) This compass, which has now been in use for some years, appears to fulfil all the conditions requisite to the full practical conditions of the mariner's compass. In the heavy seas about Cape

* Sir William Harris has investigated the magnetic conditions of this phenomenon (*Phil. Trans.*, 1831), and has shown that the restraining force with a magnet of a given power, is as the quantity of the copper within the sphere of action directly, and as the squares of the distances from the magnetic polar extremity of the needle inversely.

Horn and the Cape of Good Hope, the card was not found to oscillate more than from ¼ to ½ a point each way, and it has been found to be especially steady in steam ships fitted with the screw propeller.

(871) The following is the method of testing the compasses intended to be employed in H.M.'s ships, as adopted in the Observatory at Woolwich.*

Fig. 302.



Three pedestals, S N C. (Fig. 302), are firmly fixed in the room, quite independent of the floor, in the line of the magnetic meridian. The pedestal S carries a suspended magnet, which is observed by means of a transit telescope fixed on the centre pedestal, C; on the pedestal N is placed the compass to be examined. The collimating magnet S consists of a hollow steel cylinder ½ an inch in diameter and about 6 inches in length, centrally suspended in an appropriate frame by a long silk fibre; a small lens is fixed in the N. end of the cylinder, and there is an extremely fine scale of 160 divisions traversing it horizontally and right across its centre. The transit on the central pillar C being duly adjusted and directed in the axis of the collimating magnet, its scale is observed to vibrate across fine filaments of spider's web fixed perpendicularly in the tube of the telescope. The magnetic meridian being found by these means, the transit is turned over and directed towards the N. upon a mark painted on a distant wall on a rising ground called Cox Mount; this mark corresponds to the line of the collimating magnet on pedestal S; we thus transfer over, as it were, the line of the magnetic meridian, as taken in the telescope, upon the compass to be examined, and which is placed on the pedestal N. The needle and card being removed, the compass is so adjusted in position by the appropriate apparatus on which it rests, as to bring the point of suspension of the needle in the line of the telescope, and so bisect it; this done,

* Harris's "Rudimentary Magnetism," Part III., p. 157.

the card is replaced, and its N. pole is made also to coincide with the line of the telescope.

For the adjustment of the azimuth compasses there is a set of graduated divisions painted on the distant wall, and the vertical line of the telescope is conveyed through the window so as to cut these divisions; the prism is now adjusted for the zero point of the card, the hair line of the sight vane being directed to the particular division on the wall cut by the vertical line of the telescope.

The pivots, caps, and gimbals, and the metal of the compass bowl, &c., are now carefully examined; also the magnetic power of the needles, which are tested by a standard magnetometer of deviation, so that errors liable to arise in any particular instrument are certain to be detected.

(872) *Local Attraction.*—From what has been said respecting the temporary magnetic condition of iron under the influence of terrestrial magnetic induction, it is obvious that the compasses in ships must be subject to derangements from the large masses of iron, guns, anchors, cables, &c., on board. These derangements amount sometimes to 15° or 20°, and have exposed the vessel to the most imminent perils; indeed, there can be little doubt but that some of the most dreadful shipwrecks which are to be found recorded in our naval annals are to be ascribed to this. The loss of H.M.'s ships St. George, of 98 guns; Defiance, 74; and Hero, 74, in the winter of 1811-12, are cases in point. The Hero sailed December 18th, 1811, from Wingo Sound in the Cattegat, and instead of standing well to the westward to compensate for the deviation of the compass and the action of a north-easterly wind, steered directly the *compass course* for the Downs, the consequence was that she struck the ground in a heavy squall of wind and sleet upon Haak Sand near the Texel Island, and soon went to pieces, all on board, with the exception of eight, perishing. The St. George, which had been dismasted in the Baltic, attempted together with the Defiance to perform the same passage, unfortunately both steering a direct compass course; both ships went on shore on the western coast of North Jutland; of the crew of the former only eleven, and of the latter only six men were saved. The number of persons who suffered in these three ships, including the whole of the officers on board, amounted to nearly 2,000, being a greater loss of life in British seamen than has occurred in some of the most splendid battles in which our fleets have been engaged. In iron ships the disturbance is far more serious than in vessels built of wood; it is sometimes indeed so great as to render the compass nearly useless. Messrs. Lilley, for instance, observed in the steam ship Shanghai, one of the vessels of the Peninsular and Oriental Company,

a deviation, with the ship's head to the S., amounting in the binnacle to 171° 34′ W., being more than 15 points.

(873) A subject of such serious, we may say of such national importance, has demanded the particular attention of scientific men, but although many useful investigations have been made, the problem of compensation for local attraction as regards iron ships is not as yet satisfactorily solved. We have already alluded to Professor Barlow's "neutralizing or correcting plate," and as this method of compensation has, for wooden vessels, proved in practice eminently successful, we will now give a more particular account of the instrument (*Encycl. Brit.*, Art. Magnetism). T is a rod of copper

Fig. 303.

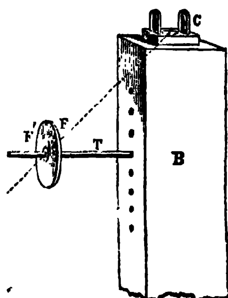
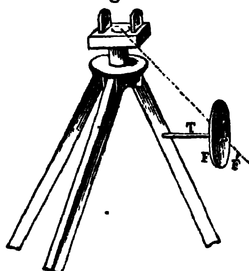


Fig. 304.



1½ inches in diameter, and F F′ two plates of iron about 12 or 13 inches in diameter, and of such a thickness that a square foot of it will weigh about 3 lbs. avoirdupois; these plates are separated by a circular sheet of card, and pressed against each other at their centre by a screw on the end of the rod T, and at their margins by 3 small screws of iron. The compass C is placed on the top of a wooden box B, and the corrector T, is placed in one of the holes in the side of the box.

The adjustment of the plate is made when the ship is lying in a calm bay near the shore; an observer with a needle and theodolite is placed at some distance from the shore, from which he can perceive the ship while she is turning her head in different directions. The compass on board the ship is under the management of another observer, with the same apparatus. At a signal given, the observer determines the angle which his own needle makes with the axis of the telescopes (one being directed to the other), which is called the central line. But as the needle on shore experiences no disturbing action, it is evident that if the needle on ship-board also experience none, the two needles will be parallel, and will form the same angle with the central line. Hence the difference between these two

angles, when they are not the same, is that which is produced by the magnetic action of the iron in the vessel from its compass needle at the instant of observation. The vessel is now made to turn round completely, and a new observation is made at every azimuth of 10 or 12 degrees; the value of the deviation produced in all positions of the ship's head upon the compass needle is thus obtained. When this is done, the observer on shore takes away his compass, and replaces it with that of the ship, which he sets on the wooden cage (Fig. 303), having different holes for receiving the axis T of the plate F′ F. As the box is turned round its axis, it carries along with it the compensator F F′, which will affect the needle of the compass C differently in different azimuths; and by a few trials it may be adjusted by means of the holes of its axis T to produce the very same deviations in the compass as was produced upon it when in the ship by the action of the iron. When it is done, the position of the centres of the plate F F′ with regard to the needle is completely marked, and when it is taken on board the ship, and placed in its proper position, the compensator is adjusted on the stand which carries the compass, so as to have exactly the same relative position as it had in the box D.

Now since the compensator produces the same effect as the iron on shipboard does, the deviation will be *doubled* in place of being corrected; but this furnishes the means of making the correction. If the variation is found to be 36° W. by the compass *without the compensator*, and afterwards 40° with the compensator, the difference 40°—36°=4° shows that the compensator augments the variation 4°, and the iron on board the vessel as much. Hence the true variation will be 36°—4=32°, or 40—4—4=32°. If the observations with the compensator had given a less result than without it, this would have shown that the action of the iron had diminished the declination, and the difference of the two observations must have been added to the first to have the true declination.*

(874) *Local Attraction in Iron Ships.*—It had been noticed by Captain Johnson that an iron ship operates on the compass needle in the same manner as a permanent magnet placed outside the vessel; this observation induced the Astronomer-Royal to direct his attention to the subject with a view to the discovery of some method of correcting the local attraction in iron vessels. The results of his inves-

* This method of correcting the compass for local attraction is not, we believe, now adopted in the Royal Navy. Either tables of errors are constructed for each ship, or the card is distorted so as to correspond with the true magnetic direction of the ship's head, the vessel being swung upon the different points of the compass.

tigations were communicated to the Royal Society, and are published in the Transactions for 1839. The experiments were made on board the iron steam ship Rainbow, and the iron sailing ship Ironsides. For the purpose of ascertaining the laws of the deviation of the compass, four stations were selected in the vessel, about 4 feet above the deck, and at these the deviations of the horizontal compasses were determined in various positions of the ship's head. All these stations were in the vertical plane, passing through the ship's keel, three being in the after part of the ship, and one near the bow. Observations were also made for determining the horizontal intensity at each of the stations. The deviations of dipping needles at three of these stations were also determined, when the plane of vibration coincided with that of the ship's keel, and also when at right angles to it. The most striking feature in the results as to the disturbance of the horizontal compass at the four stations, was the very great apparent change in the direction of the ship's head as indicated by the compass nearest the stern, corresponding to a small real change in one particular position; the former change being 97°, whereas the latter was only 23°; and the small amount of disturbance indicated by the compass near the bow.

Any attempt to discuss Mr. Airy's elaborate mathematical investigation would be quite foreign to the object of this work.

(875) The fundamental supposition of the theory of induced Magnetism on which he rests his calculations is, that by the action of terrestrial Magnetism, every particle of iron is converted into a magnet, whose direction is parallel to that of the dipping needle, and whose intensity is proportional to that of terrestrial Magnetism; the upper end having the property of attracting the N. end of the needle, and the lower end that of repelling it. He deduces the following simple rule for the correction of a compass disturbed by the induced Magnetism only of the iron in a ship: —

1. Determine the position of Barlow's plate with regard to the compass, which will produce the same effect as the iron in the ship.

2. Fix Barlow's plate at the distance and depression determined by the last experiment, but in the opposite azimuth.

3. Mount another mass of iron at the same level as the compass, but on the starboard or larboard side, and determine its position so that the compass points correctly when the ship's head is N.E., S.E., S.W., or N.W.; then the compass will be correct in all positions of the ship's head, and in all magnetic latitudes.

When the disturbing iron of the ship is at the same level as the compass, the correction is stated to be much more simple, it being then only necessary to introduce a single mass of iron at the star-

board or larboard side, and at the same level as the compass; but in the construction of the ship, and in the fixing of correctors, no large mass of iron should be placed below the compass.

(876) In his experiments on the ship Ironsides, Mr. Airy corrected one of the compasses by a tentative process, which he considers likely to be of the highest value in the correction of compasses of iron ships in general. The ship's head being placed exactly N. as ascertained by a shore compass, a magnet was placed upon the beam from which the compass was suspended, with the direction of its length exactly transverse to the ship's keel; it was moved upon the beam to various distances, till the compass pointed correctly, and then it was fixed. Then the ship's head was placed exactly E. and another magnet, with its length parallel to the ship's keel, was placed upon the same beam, and moved to different distances till the compass pointed correctly, and then it was fixed. The correction for induced Magnetism was neglected, but there would have been no difficulty in adjusting it by the same process, placing the vessel's head in azimuth 45°, or 135°, or 225°, or 315°. The deviations of the compass are caused by two modifications of magnetic power; the one being the independent Magnetism of the ship which retains, in all positions of the ship, the same magnitude and the same direction relatively to the ship; the other being the induced Magnetism, of which the force varies in magnitude and direction when the ship's position is changed. In the cases investigated by Mr. Airy, the effect of the former force was found greatly to exceed that of the latter. The most remarkable result, in a scientific view, of Mr. Airy's investigation, is the great intensity of the permanent Magnetism of the malleable iron of which the ship is composed. It appears, however, that almost every plate of rolled iron is intensely magnetic.

(877) The Rev. Dr. Scoresby, whose unceasing labours in the service of practical magnetics we have had occasion repeatedly to refer to, has devoted much study to the variation of the compass in iron vessels.* He considers that the adjustment of the compasses of iron ships by fixed permanent magnets is not only delusive but dangerous. Iron becomes magnetic by virtue of the inductive influence of the earth, but its Magnetism might be controlled, altered, or destroyed, by mechanical action (859—861). Applying this to the case of iron ships, Dr. Scoresby considers that, in consequence of the percussive action to which the material is exposed while the ships are in course of construction, it becomes as intensely magnetic as it

* Vide "Magnetical Investigations," vol. ii.; also, Reports of the Proceedings of the British Association at Oxford in 1847, and at Liverpool in 1854.

is possible for malleable iron to do. This augmented Magnetism is not, however, permanent or fixed, but under different circumstances as to the relative deviation of the ship's Magnetism and that of the earth, is easily changeable, and liable necessarily to be changed. Experiments on rolled iron plates of the same kind as those of which ships are generally built, showed that in them the Magnetism was changeable and controllable like that in bar iron under the requisite change of position, by vibratory or percussive action. Dr. Scoresby likewise made experiments on a portion of a plate cut out of the side of a ship recently built, and the results of his observations was to establish the fact that, besides the two denominations of Magnetism ordinarily received, that of simple terrestrial induction, and that of permanent independent Magnetism, there was another denomination corresponding with neither, not being absolutely controllable, like the former, by terrestrial influences, nor capable, like the latter, of resisting all kinds and modes of mechanical violence. To this denomination he gives the name of *retentive* Magnetism. The vibration of a ship in a heavy sea is sufficient to change the original Magnetism developed and augmented in the course of her construction. A great deal will depend on the position in which the ship has been built. If, for instance, she has been built with her head to the N.E., she will have a certain magnetic distribution, but when she begins to strain with her head to the S.W., that distribution will become changed, and the first effect will be to alter the compasses adjusted by fixed magnets. All attempts, therefore, to adjust a transient influence by a permanent one, only aggravate the error which it is sought to overcome, and captains of ships should lose no opportunity of correcting and verifying their compasses whenever the sun or a star is in sight. A compass should likewise be kept aloft, as far as possible from the iron of a ship, as a standard for reference. Another objection that has been raised to the Astronomer-Royal's system is, that the magnetic poles of the compensating magnets are liable to change or vary in their intensity.

The Magnetism of iron ships is thus changeable in all its qualities, the most enduring being of a description changeable under severe straining and mechanical violence; this Scoresby calls "*retentive Magnetism.*" His suggestions are :—

1°. A standard azimuth compass to be placed on a high pedestal where (on the Admiralty plan) a position of small deviation may be found.

2°. A compass at the mast-head for reference will be best of all.

3°. The wheel compass required for ships engaged in the home trade, or traversing mainly parallels of latitude, not southward of the

Mediterranean, if adjusted with magnets and pieces of iron, may not then be unsafe, where reference may always be had to the standard for verification.

4°. No standard compass in great distances.

5°. Care in selection of compasses to have ample directive force. His improvement had trebled the directive force weight for weight of the compasses used in the Navy up to 1849 or 1850.

6° Captains should be made to take observations for verifying their compasses by azimuth compasses, stars, position of land, &c.

7°. Captains should have a special knowledge for the charge of iron ships; for here, in addition to the ordinary dangers of navigation, is a new source of error and misguidance, as to which it is most important he should never be thrown off his guard.*

* A most lamentable instance of the loss of an iron ship in consequence of changes in the action of her compasses, occurred in the early part of the year 1854. The circumstances were as follow: The ship, Tayleur, a new vessel bound to Australia, sailed from Liverpool on Thursday, 19th January; she was 1,979 tons burden new measurement, and she had on board 458 passengers—the crew and passengers together making a total of 528 persons. She left the Mersey about noon, and the pilot left her between seven and eight o'clock in the evening in a position between Point Lynas and the Skerries. On Friday she encountered very heavy weather, and about eight o'clock on the following morning it was for the first time ascertained that there was any material difference between her compasses. One was near the helmsman, and was the one by which he was steering; the other was near the mizen mast. Both of these compasses had been adjusted by permanent magnets, so that if the principle of adjustment had been correct, they should not either have changed or differed from each other. Trusting to the compass near the helmsman, the captain had the idea firmly impressed upon his mind that he was sailing fairly down almost mid-channel; at all events, in a good position for navigating the Irish channel. The other compass indicated a difference of about two points; the captain, however, judging from certain indications which he had noticed previously, assumed that the wheel compass was the correct one. In the course of a few hours—about half-past eleven o'clock on the same morning—the wind having increased and a heavy sea setting up the channel, the ship made rather a rapid progress, when they came suddenly in sight of land on the lee beam in such a position that there was necessarily a great difficulty—in this case (according to the measures pursued), an insurmountable difficulty—in avoiding the land. An attempt was made to wear the ship round; this failed, and then an attempt was made to use the anchors to bring her up. Both the cables snapped on the occasion, and the ship was thus left helpless, driving broadside upon the rocks of Lambay Island. The result was the fearful catastrophe of the loss of about 290 lives! Inquiries were instituted by the Board of Trade in two departments; one by means of Captain Walker of the Navy, who ascribed the loss of the vessel to the captain's supposition that the compass by the helm was correct; the other by means of the Marine Board of Liverpool, who reported that although the captain had given very great attention to the ascertaining of the correctness of his compasses, yet the Tayleur was

(878) To these observations of Dr. Scoresby, Mr. Airy has made a reply (*Athenæum*, Oct. 28, 1854) to the following effect: He objects to the term "retentive" or "retained" Magnetism, as representing the characteristics of the Magnetism of wrought iron plates, which appears to him to differ very little from the Magnetism of hard steel bars. Both are magnetized by induction, and both are liable to have their Magnetism weakened or reversed; but as in practice the Magnetism of an iron ship is slightly more liable to change than that of a carefully preserved steel bar, he would call it "sub-permanent polar." He thinks it likely that the striking character of Dr. Scoresby's experiments, produces an impression of the extent of their applicability to iron ships, far greater than is warranted by careful consideration. We may speak poetically of the shocks which a ship receives from the waves, but, in reality, the plates of iron of which a ship is composed sustain no such shocks. The direct effect of the most violent sea upon them is this: that in the course of two or three seconds of time, the plate is plunged 5 or 6 feet deeper in the water, and sustains the corresponding hydrostatic pressure. This is very different indeed from the raps or slaps in Dr. Scoresby's experiments, in which it is essential that the blow be of the nature of *impact*, occupying a very small fraction of a second of time. Probably the strain of extension to which the plates are subjected may produce a greater effect; on this, however, experiments are wanting. But even here the change in the state of extension is not sudden, but gradual. The tremor produced by steam power is more likely to affect the plates in some parts of the ship. It is evident that there are causes in action tending to produce effects like those exhibited in Dr. Scoresby's experiments; and it is equally evident that the action of those causes must be exceedingly slow. The change to be expected in a ship's sub-permanent Magnetism in sailing from England to the Cape of Good Hope, does *not* essentially depend on her passing into another magnetic hemisphere. It *does* depend mainly on this circumstance: that supposing her to have been built with her head to the north, or in the line of *boreal* Magnetism, she is then turned with her head to the south, or in the line of *austral* Magnetism, and is so kept exposed to slight tremors for one or more months. If she had been moored off the coast of Portugal for the same time, in the same position, and exposed to the same tremors, Mr. Airy believes that her Magnetism would have undergone nearly the same change

brought into the dangerous position in which the wreck took place, through the deviation of the compasses—the cause of which, they (the Marine Board) had been unable to determine.—*Report of the Twenty-fourth Meeting of the British Association, Liverpool—Athenæum.*

(as regards horizontal deviation of the compass) as in the voyage to the Cape of Good Hope.

(879) Mr. Airy adverts to the following two sources of error to which his method of correcting compasses may be liable, if due care is not exercised. The first is, that captains are hardly aware that a very trifling disturbance in the position of the compass (for instance, a change of a quarter of an inch in the height) may very greatly disturb the neutralizing influence of the magnets. The second is, that the artists who correct the compasses are too much inclined to place the correcting magnets in the position called "end on." In this position the magnet exerts greater deflective power, but it also introduces a force perpendicular to the ship's deck; and this force, when the ship reels, produces an uncorrected horizontal disturbance. While the building in iron was principally confined to paddle steam ships, this was not important; but now, when so many screw steam ships and sailing ships are built of iron, this arrangement ought never to be used.

(880) To the important question—What (under all circumstances) is it best to do now? Mr. Airy answers by asserting, in the first place, that the source of local disturbance and its laws are perfectly well known: that the disturbance can be neutralized by well known means to the greatest exactness; and that this neutralization is perfect during change of time and change of place, until the ship herself undergoes an organic change. In the next place, he protests strongly against the system now generally in use in the Royal Navy, of using a table of errors, and thus constantly making numerical corrections, instead of at once making a mechanical correction. 1°. It is baffling to the mariner. 2°. It is liable to exactly the same errors, in the event of a change in the ship's sub-permanent Magnetism, as the system relying on the mechanical correction. 3°. It is liable to errors peculiar to itself, which would be entirely avoided by the use of mechanical correction. 4°. In extreme cases it cannot be used at all; thus, in the Greenland seas the compasses would sometimes turn round with the ship; whereas, there are in the Greenland seas several iron ships with correcting magnets effecting their purpose successfully. 5°. In cases not so extreme, the inconvenience is intolerable; thus, in one instance which came under Mr. Airy's own eyes, the compass changed 100° with a very small motion of the ship; and the directive intensity in one position was only $\frac{1}{10}$th of what it was in another position: these inconveniences are entirely remedied by the correcting magnets.

(881) After a due consideration of the whole matter, Mr. Airy has come to the following conclusions: For voyages of moderate

duration, as, for instance, not farther than to the Mediterranean, or to the northern parts of N. America, no improvement can be made in the existing system, except in the details above alluded to. The "end on" position of the magnets ought to be forbidden, and some attention ought to be given to the ship's sub-permanent Magnetism in the direction perpendicular to the deck. For voyages of greater duration, as to the Plata, the Cape of Good Hope, &c., he thinks it desirable that means should be provided for enabling the captain to make the small changes which may be required in the correcting magnets, and he undertakes to point out a practical course by which this can be effected. He thinks that some general supervision should be exercised by the Board of Trade over the correction of the compasses in iron ships, and that the Marine Board of Liverpool should interest themselves in the matter. He volunteers his assistance, and expresses his conviction that with the sanction of one liberal ship-owner, the aid of one intelligent captain, and the command of one ship for a few days, he could arrange everything with good hope of complete success. The above remarks are intended to apply to *iron*-built ships only, in which the sensible part of the disturbance of the compass is produced almost entirely by the ship's sub-permanent Magnetism. In wood-built ships, in which the *induced* Magnetism is the principal disturbing power, the rules of correction are necessarily different; here, however, Mr. Airy also disapproves of the use of a table of errors, and prefers that of mechanical correction; the nature of which, as applicable to the neutralization of induced Magnetism, is perfectly understood.*

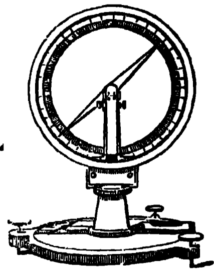
(882) *The Dipping Needle.*—The important fact that a magnetized needle when allowed perfect freedom of motion endeavours to place itself in the plane of the magnetic meridian in a direction more or less inclined to the horizon, was discovered about the year 1756, by Robert Norman, an optician, of London; but many years elapsed before it was known that this inclination of the needle was subject to a variation; this interesting fact has, however, been well ascer-

* Dr. Scoresby has undertaken a voyage to Australia with an express view of performing experiments in the southern hemisphere; the directors of the Liverpool and Australian Navigation Company having granted him the use of a state cabin in their splendid screw steamer The Royal Charter, a vessel well adapted for investigations of this nature. The masts are of wood. The compasses are so arranged as to check each other. The wheels are, it is said, not likely to influence even delicate experiments. Dr. Scoresby sailed in January (1856).

Mr. Hyde, of the Cumberland Iron Works, Bristol, is reported (*Times*, Tuesday, December 11th, 1855) to have solved the difficulty of the variation of the compass in iron ships, by placing the compass in a neutral position in the vessel where the Magnetism of the iron in the afterpart is exactly balanced.

tained, and various instruments, called *dipping needles*, have been constructed, with a view of ascertaining the amount of the *dip* in different places at the same time, or in the same place at different times; but it was not until the latter end of the last century that sufficient accuracy could be carried into their construction to render them fully competent to the delicate task they were intended to perform. A simple form of the dipping needle is shown in Fig. 305. It consists of a brass plate supported on a flat stand by 3 screws; on this plate is placed a spirit-level for adjusting the plate horizontally; a stout hollow brass pillar rising from the centre of the plate carries a circular box, forming the case of the dipping needle, which turns freely on two finely polished planes of agate.

Fig. 305.



(883) It is very rarely, however, that a needle can be so nicely balanced as to give the exact dip at a single observation. The usual mode of proceeding is, therefore, as follows: Having taken eight or ten observations, turn the needle completely round; viz., if in the first instance the face was towards E., turn it now to W.; if it was before W., turn it to E.; this is very easily effected by the graduations on the lower limb of the instrument. Here, again, the same number of observations are to be taken, in the same manner as above, which, from slight defects of construction, may not agree precisely with the former; let, however, the mean in both cases be preserved by dividing the sum of each set of observations by the number of them. The needle is now to be removed from the box, and its poles inverted by any of the usual methods of magnetizing; so that when replaced on its axis, that end which was before below the horizon will now be above it, and if the needle be correctly balanced, by exactly the same quantity; but if not, as is most likely to happen, we must get two other means, as above, and the general mean of the four will be very nearly, or exactly, the true dip.

(884) It is easy to see how the least possible defect in the axis, or the interposition of the smallest particle of dust will be sufficient to stop the motion of the needle, and lead to inaccuracy in the results; for if we examine the nature of the force by which the needle is brought into its direction, we shall see that it varies as the *sine of the angle* between its true position and that in which it is actually found at any time, and therefore when the needle is, say 15′ of its natural position, the lever by which the power is communicated to the needle is only equal to the sine of 15′, or the power of the

terrestrial Magnetism on the needle in this position is to the same when the latter is at right angles to the dip, as radius to sine 15′, or as 1 : ·0043. (*Barlow.*)*

(885) *The Variation Compass.*—This instrument being only intended for measuring small changes in the declination of the magnetic needle, either annual or diurnal, is more limited in its arc of vibration, and is generally longer than the needle used for common purposes; it is also furnished with conveniences for reading closer than the ordinary compass; otherwise any needle so mounted and furnished as to be very sensible and capable of being read off to minute divisions, might be used as a variation compass. In general, however, needles intended for this purpose are constructed in a particular manner, having only a very small part of the circle graduated, and the means of distinguishing small changes better suited to the eye than they generally are in common horizontal needles. The place in which the instrument is fixed is required to be particularly firm and steady, and in short, every precaution is necessary to be had recourse to in order to avoid small irregularities, because the changes to be observed are in themselves so small that without the greatest accuracy they may be either overlooked, or the irregularities of the instrument may so combine them, that every attempt to deduce laws from them would be unavailing.†

(886) *The Declination Magnet.*—This instrument as constructed by Professor Gauss, of Göttingen, consists of a prismatic magnetic bar, suspended by untwisted threads of raw silk. To the S. or N. end of the bar a plane mirror is fixed, and it is enclosed in a wooden cylindrical box, which besides the small aperture in the lid for the passage of the thread, has a larger one in the side, which is rather higher and wider than the mirror. Opposite the mirror a theodolite is placed, the vertical axis of which is in the same magnetic meridian with the line of suspension, and at a distance from it of about 16 Parisian feet. To the stand of the theodolite is fixed a horizontal scale of 4 feet in length, divided into single millimetres: it makes a right angle with the magnetic meridian. That point of the scale which is situated in the same vertical plane with the optical axis of the telescope, and which may be called the zero point, is marked out by a fine thread of gold depending from the middle of the object glass, and charged with a

* For a description of a beautiful dipping-needle deflector invented and used by Mr. Fox for measuring the variation and dip of the needle, and the magnetic intensity, see the *Report of the Royal Cornwall Polytechnic Society for* 1835.

† The most perfect variation compass is, probably, that employed by Colonel Beaufoy, for a description of which see *Annals of Philosophy*, 1818.

weight. The scale is fixed at such a height that the image of a portion of it is seen in the mirror through the telescope, the eye-glass of which is adjusted accordingly. At the opposite side from the needle, in the same vertical plane, and at a distance from the telescope equal to that of the image, a mark is fixed serving every instant to ascertain the unchanged position of the theodolite. It is obvious that if all these conditions be fulfilled, the image of the zero point on the scale will appear exactly on the optical axis of the telescope, and that so far as an object of known azimuth is visible at the place of the theodolite, we may by means of this instrument immediately find the absolute magnetic declination. If, on the other hand, these conditions are only partially fulfilled, then generally speaking, the image not of the zero point, but that of another point of the scale, will appear on the optical axis; and if the horizontal distance of the scale from the mirror, have been measured with exactness, it will be easy to reduce the amount of the divisions of the scale to the corresponding angle, and thus to correct the result first obtained. By turning the needle in the stirrup so that the upper surface becomes the lower, the amount of the error of collimation of the mirror may be ascertained with great ease and precision. By this mode of operating the direction of the needle and its variations are determined with the greatest possible precision.

(887) *The Horizontal Force Magnetometer.*—In this instrument, which is intended to measure the changes which occur in the directive force of the needle, the magnetic bar is suspended by two parallel bundles of unspun silk fibres, by twisting which the bar is forced into a position perpendicular to the magnetic meridian, and maintained *in equilibrium* by the opposition of two equal forces; the reactive force of the suspension tending to untwist the silk, and the magnetic force of the bar by which it seeks to recover its normal position. Now, as the first of these forces is constant, it is evident that any change of the latter will give rise to small movements in the position of the bar; these movements are read off by a telescope directed towards a mirror attached to the centre of the bar, and variations in the horizontal magnetic force are thus determined.

(888) *The Vertical Force Magnetometer.*—The object of this instrument is the measurement of the vertical component of the magnetic force and its momentary changes, without knowing which it is impossible to conclude anything as to the real nature, amount, and direction of the perturbative forces. It is a species of magnetic balance in which a needle or magnetized bar placed in the magnetic meridian, is coerced by the action of small weights from its natural

direction to a horizontal one. This condition renders it possible to rest it by knife-edges invariably fixed in, and forming a part of it, on planes of agate, and thus to secure for it in all geographical positions, the same delicacy, sensibility, and freedom of motion which belong to the ordinary balance. Thus coerced, adjusted, and counterpoised, whatever movements take place in it, are referable directly to changes in the amount of the vertical magnetic force which opposes, and in its mean situation neutralizes, the action of the weights. The bar carries over and across its axis a small mirror, and the movement being read off by a microscope and subjected to calculation, affords a measure of the amount of those changes. This beautiful instrument is considered by its inventor, Mr. Lloyd, to be capable of detecting a change to the extent $\frac{1}{40000}$th of the total magnetic intensity.*

* The labour of registering magnetical observations has been lately relieved by photography—perhaps the most valuable application of that beautiful art. Two methods are in use: that of Mr. Brooke, for a description of which see Bird and Brooke's "Elements of Natural Philosophy," p. 271; and that of Mr. Ronalds, for which see *Phil. Trans.*, 1847, p. 111.

CHAPTER XVII.

MAGNETISM—(CONTINUED).

Magnetical observations—Humboldt's researches—The declination of the horizontal needle—Isogonic lines—Periodic variations—Sabine's researches—The inclination of the needle—The magnetic equator—Terrestrial magnetic intensity —Magnetic storms—Theory of terrestrial Magnetism.

(889) IN April, 1836, Baron Alexander Von Humboldt addressed a letter to His Royal Highness the Duke of Sussex, President of the Royal Society of London, to solicit the co-operation of that body towards the advancement of the knowledge of terrestrial Magnetism, by the establishment of magnetic stations and corresponding observations, and soliciting it to extend, in the colonies of Great Britain, the line of simultaneous observations; these stations he proposed to be established, either in the tropical regions on each side of the magnetic equator, or in the high latitudes of the southern hemisphere and Canada.

This distinguished traveller had been for many years much occupied with the phenomena of the intensity of the magnetic forces; and the inclination and declination of the magnetic needle. During the years 1806 and 1807, particularly at the periods of the equinoxes and solstices, he measured the angular alterations of the magnetic meridian, at intervals of an hour, often of half an hour, without interruption, during four, five, and six days, and as many nights, in a large garden at Berlin. The instrument he employed was a magnetic telescope (*lunette aimantée*) of Prony, capable of being reversed upon its axis, suspended according to the method of Coulomb, placed in a glass frame, and directed towards a very distant meridian mark, the divisions of which, illuminated during the night, indicated even six or seven seconds of *horary* variation. In verifying the habitual regularity of a *nocturnal period*, he was struck with the frequency of the perturbations, especially of oscillations, the amplitude of which extended beyond all the divisions of the scale, and which occurred repeatedly at the same hours before sunrise, the violent and accelerated movements of which could not be attributed to any acci-

dental mechanical cause. These vagaries of the needle, the almost periodical return of which were subsequently confirmed by M. Kupffer, appeared to Humboldt the effect of a reaction of the interior of the earth towards the surface of *magnetic storms*, which indicate a rapid change of tension. From that time, he says, he has been anxious to establish on the E. and W. of the meridian of Berlin apparatus similar to his own, in order to obtain corresponding observations, made at great distances, and at the same hours.

(890) In 1827, Baron Humboldt renewed these observations at Berlin, and endeavoured at the same time to generalize the means of simultaneous observations, the accidental employment of which had produced such important results. One of Gambey's compasses was placed in the *magnetic pavilion*, in which no portion of iron was introduced, which had been erected in the middle of a garden. At his request, the Imperial Academy and the curator of the University of Cazan, erected *magnetic houses* at St. Petersburg and at Cazan, and the Imperial Department for Mines having concurred in the same object, *magnetic stations* were successively established at Moscow, Barnaoul, and at Nertschinsk. The Academy of St. Petersburg did still more, and sent a courageous and clever astronomer, M. George Fuss, the brother of its perpetual secretary, to Pekin, and procured the erection there of a *magnetic pavilion* in the convent garden of the monks of the Greek church. Subsequent to the return of M. Fuss, M. Kowanko continued the observations of horary declination, corresponding to those of Germany, St. Petersburg, Cazan, and Nicolajeff in the Crimea, where Admiral Greigh had established one of Gambey's compasses, the care of which was confided to the director of the observatory, Mr. Knorre. A magnetic apparatus was also established at the depth of 35 fathoms, in an adit in the mines of Freiberg, in Saxony, where M. Reich, to whom we are indebted for valuable experiments and observations upon the mean temperature of the earth at different depths, made observations at regulated intervals. Observations of horary declination, made at Marmato, in the province of Antioquia, in South America, in N. latitude 5° 27′, in a place where, as at Cazan, and Barnaoul in Asia, the declination is E., have been transmitted by M. Boussingault; while on the N.W. coasts of the new continent, at Sitka in the Russian settlements, Baron Von Wrangal, also provided with one of Gambey's compasses, took part in the simultaneous observations made at the time of the solstices and equinoxes. Magnetic apparatus were also sent by Baron Humboldt to Havannah and Cuba; and M. Arago erected a compass, at his own expense, in the interior of Mexico, where the soil is elevated 6,000 feet above the level of the sea. A magnetic station in Iceland has also been established.

(891) The suggestions of Baron Humboldt received from the Royal Society the attention which they merited; and a committee was appointed for carrying his recommendations into effect. Comformably with the report made by this committee, the ten following places were fixed on by the council as being the most eligible for carrying on magnetic observations according to the plan recommended by Baron Von Humboldt: Gibraltar, Corfu, Ceylon, Hobart Town, Jamaica, Barbadoes, Newfoundland, Toronto, Bagdad, and the Cape of Good Hope; these places being permanent stations, where officers of engineers and clerks are always to be found. The council also determined that for the present the observations of Magnetism may be limited to those of the direction of the magnetic needle. "I could hardly," says Humboldt ("Cosmos," Sabine's Transl., vol. i., p. 419) "entertain the hope when I first proposed to establish a system of observatories, that I should live to see the time when, thanks to the united activity of excellent physicists and astronomers, and especially to the munificent and persevering support of two governments, the Russian and British, both hemispheres should be covered with magnetic observatories. From Toronto, in Canada, to the Cape of Good Hope and Van Diemen's Land, and from Paris to Pekin, since 1828, the globe has been covered by magnetic observatories, in which every movement or manifestation, regular and irregular, of the earth's magnetic force is watched by uninterrupted and simultaneous observation. A variation of $\frac{1}{10000}$th of the magnetic intensity is measured. At certain epochs, observations are taken at intervals of $2\frac{1}{2}$ minutes, and are continued during 24 consecutive hours. A great English astronomer and physical philosopher has computed that the mass of observations to be discussed amounted in three years to 1,958,000. Never before has an effort so grand and so worthy of admiration, been made to investigate the *quantitative* in the laws of one of the great phenomena of nature. . . . . . I need not dwell on how deeply science is indebted to the great and zealous exertions, on this occasion of Herschel, Sabine, Airy, and Lloyd, and to the powerful support of the British Association for the Advancement of Science at its meeting at Newcastle in 1838. In June, 1839, the Magnetic Antarctic Expedition was determined on, and placed under the command of Captain James Clark Ross. It returned crowned with success and honour; having enriched science with most important geographical discoveries in the vicinity of the Southern pole, with simultaneous observations on eight or ten magnetic term days, and with a determination of the lines of equal declination, equal inclination, and equal force for three-

fourths of the accessible portion of the high latitudes of the Southern hemisphere."*

(892) The magnetic apparatus with which each station is provided, consists of the three magnetometers above described. Each day is, in the first place, supposed to be divided into 12 equal portions of 2 hours each, commencing at all the stations at the same instants of absolute time, which may be called the magnetic hours, viz., 0 h. 0 m. 0 s., 2 h. 0 m. 0 s., 3 h., &c., of *mean time at Göttingen*, without any regard to the apparent *times of the day at the stations themselves*, which will, of course, differ by their differences of longitude, so that the first magnetic hour which at Göttingen commences at noon will at Dublin (1 h. 5 m. 8 s. *west* of Göttingen) commence at 10 h. 54 m. 52 s.; at Madras (4 h. 41 m. 42 s. *east* of it) at 4 h. 41 m. 42 s. p.m. The magnetometers are read off at the commencement of every magnetic hour, day and night, Sundays excepted; and to multiply opportunities for observing remarkable coincidences, the observation at 2 h. p.m. Göttingen mean time, is in all cases, a triple one, the magnetic readings being thrice repeated in a given order, at intervals of 5 minutes.

(893) The magnetical observatory erected in Dublin under the superintendence of Professor Lloyd, is situated in an open space in the gardens of Trinity College, and sufficiently remote from all disturbing influences. The building is 40 feet in length, by 30 in depth. It is constructed of the dark-coloured argillaceous limestone, which abounds in the valley of Dublin, and which has been ascertained to be perfectly devoid of any influence on the needle. This is faced with Portland stone; and within, the walls are *studded*, to protect from cold and damp. No iron whatever is used

* The following summary of the magnetic observatories co-operating in the proposed plan in 1840, will serve to show the spirit with which the subject was taken up—and many more stations have since been added:—

British Stations.—Dublin, Toronto, St. Helena, Cape of Good Hope, Van Diemen's Land, Madras, Simla, Singapore, Aden, with each ship of the naval expedition under Captain Ross.

Russian.—Boulowa, Helsingfors, Petersburg, Sitka, Catherineberg, Cazan, Barnaoul, Nertschinsk, Nicolajeff, Tiflis, Pekin.

Austrian.—Prague, Milan.

United States.—Philadelphia, Cambridge.

French.—Algiers.

Prussian.—Breslau.

Bavarian.—Munich.

Belgian.—Brussels.

Egyptian.—Cairo.

Hindostan.—Trevandrum.

Russia has ever taken a warm interest in the advance of terrestrial Magnetism: as early as 1829, Humboldt succeeded in procuring the establishment of observatories at most of the above-named places, which have existed ever since.

throughout the building. With reference to the materials, Professor Lloyd mentions, that in the course of the arrangements for the erection of a magnetical observatory at Greenwich, Mr. Airy had rejected bricks in the construction of the building, finding that they were in all cases magnetic, and sometimes even *polar*. Mr. Lloyd has since confirmed this observation, by the examination of specimens of bricks from various localities; and though there appeared to be great diversity in the amount of their action on the needle, he met with none entirely free from such influence.

The building consists of one principal room, and two smaller rooms, one of which serves as a vestibule. The principal room is 36 feet in length, by 16 feet in breadth, and has projections in its longer sides which increase the breadth of the central part to 20 feet. This room contains four principal instruments, suitably supported on stone pillars: viz., a transit instrument, a theodolite, a variation instrument, and a dipping circle. The transit instrument (4 feet in focal length), is stationed close to the southern window of the room. In this position it serves for the determination of the time; and a small trap-door in the ceiling enables the observer to adjust it to the meridian. The theodolite is situated towards the other end of the room, and its centre is on the meridian line of the transit. The limit of the theodolite is 12 inches in diameter, and is read off by 3 verniers to 10 seconds. Its telescope has a focal length of 20 inches, and is furnished with a micrometer reading to a single second, for the purpose of observing the *diurnal variation*.

The variation instrument is placed in the magnetic meridian with respect to the theodolite; the distance between these instruments being about 7 feet. The needle is a rectangular bar, 12 inches long, suspended by parallel silk fibres, and enclosed in a box to protect it from the agitation of the air. The magnetic bar is furnished with an achromatic lens at one end, and a cross of wires at the other, after the principle of the collimator. This is observed with the telescope of the theodolite in the usual manner; and the deviation of the line of collimation of the collimator from the magnetic axis, is ascertained by reversal. The direction of the *magnetic* meridian being thus found, that of the true meridian is given by the transit. It is only necessary to turn over the transit telescope, and using it also as a collimator, to make a similar reading of its central wire by the telescope of the theodolite; the angle read off on the limb of the theodolite is obviously the supplement of the variation. The use of the transit was suggested by Dr. Robinson; and it was anticipated that much advantage would result from the circumstance, that the two extremities of the arc are observed by precisely the

same instrumental means. With this apparatus observations of the *absolute variation* are made twice each day, as is done in the observatory of Professor Gauss, at Göttingen, the course of the *diurnal variation*, and the hours of maxima and minima, having been ascertained by a series of preliminary observations with the same instrument.

A dipping circle, constructed by Gambey, is placed on a pillar at the remote end of the room; and is furnished with a needle, whose axis is formed into a knife edge, for the purpose of observing the diurnal variations of the dip. Gauss's large apparatus is also set up in the same room, and is used occasionally, especially in observations of the *absolute intensity* made according to the method proposed by that distinguished philosopher.

The bars are too large to be employed in conjunction with other magnetical apparatus.

(894) The magnetic force of the earth exhibits itself at the surface in three classes of phenomena: 1st. In a variation in direction shown by the *declination* of the horizontal needle; 2nd. By a variation in the inclination of the needle in a vertical plane; 3rd. By a variation in the intensity of the force. Lines of equal declination are called *isogonic* lines; lines of equal dip, *isoclinal*; and lines of equal force, *isodynamic lines*. The absolute and relative positions of these lines are undergoing continual changes, so irregular and complicated, that a few years suffices to alter their form and position.

(895) *The Declination.* — Measures of the variation of the needle have been taken by navigators and travellers in all parts of the globe. In some places the magnetic and terrestrial meridians exactly correspond; in these situations the needle points to the true N. and S.; but in most parts of the earth's surface its direction deviates, sometimes to the E., and sometimes to the W. We are indebted to Professor Hansteen for the first satisfactory collection of observations on the variation of the needle, and for the first philosophical generalization of them. He has published a variation chart for 1787, in which it is shown how irregular are the causes on which terrestrial Magnetism depends, by the total want of symmetry, and the irregularities and inflexions of the magnetic curves. He makes the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true N., to begin in latitude 60° to the W. of Hudson's Bay, proceeding in a S.E. direction through the North American Lake, passing the Antilles and Cape St. Roque, till it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich at about 65° of S. latitude. This line of no variation is extremely regular, being

almost straight till it bends round the eastern part of South America, a little S. of the equator. On the other hand, his chart shows that the *eastern line of no variation* is extremely irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° S., below New Holland, crosses that immense island through its centre, extends through the Indian Archipelago with a double sinuosity, so as to cross the equator three times; first passing N. of it to the E. of Borneo, then returning to it and passing S. through Sumatra and Borneo, and then crossing it again beneath Ceylon, from which it passes to the E. through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the W. till it reaches the latitude of 70°, where it descends again to the S., and returns northward with a great semicircular bend, which terminates in the White Sea.

These lines of no variation—*agonic* lines as they are called—are accompanied through all their windings by other lines where the variation is 5°, 10°, 15°, &c.; these lines becoming more irregular as they recede from those of no variation. Their position is not stable, being sensibly altered after the lapse of considerable periods of time.

(896) In 1833, Professor Barlow constructed a new variation chart, in which he has inserted the magnetic observations of Commander Ross; and he remarks, that the very spot where this officer found the needle perpendicular, "that is, the pole itself, is precisely that point in my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately and conjointly as a system."

(897) Hansteen is of opinion, that there are *four points of convergency* in each hemisphere; and that these points are to be considered as the *four magnetic poles of the globe.* He concludes that they have a regular motion round the globe; the two northern ones from W. to E., in an oblique direction; and the southern ones from E. to W., also obliquely. The following are the calculated periods of their revolution:—

The strongest *north* pole in 1740 years.
The strongest *south* pole in 4609 years.
The weakest *north* pole in 860 years.
The weakest *south* pole in 1304 years.

Hansteen considers the four poles as originating in *two* magnetic axes, the two strongest being the termination of one axis, and the two weakest of the other; and he conceives that they may have been produced, either along with the earth itself, or at a later epoch. Accord-

ing to the first supposition, it is not easy to account for their change of position; but according to the last, they must have originated either from the earth alone, or from some external cause. If they originated in the earth, their change of position is still unsusceptible of explanation; and hence Hansteen conceives that they have their origin from the action of the sun heating and illuminating the earth, and producing a magnetic tension as it produces electrical phenomena.

(898) The following table exhibits the progressive changes in the variation of the needle, which have taken place in London from 1576 to 1831, and in Paris from 1541 to 1829, and in Brussels from 1827 to 1849:—

Years.	Observers.	Variations.			
London:—					
1576	Norman	11°	15′		Easterly.
1580	Burroughs	11	17		Maximum.
1622	Gunter	6	12		„
1634	Gellibrand	4	5		„
1657 } 1662 }		0	0		No variation.
1666		0	34		Westerly.
1670		2	6		„
1672		2	30		„
1700		9	40		„
1720		13	0		„
1740		16	10		„
1760		19	30		„
1774		22	20		„
1778	Phil. Trans.	22	11		„
1790		23	39		„
1800		24	36		„
1806	Phil. Trans.	24	8		„
1813	Col. Beaufoy	24	20	17″	
1815	Ditto	24	27	18	Maximum
1816		24	17	9	„
1820		24	11	7	„
1823		24	9	40	„
1831		24	0	0	„
Paris:—					
1541		7	0		Easterly.
1550		8	0		
1580		11	30		Maximum.

Years.		Variations.		
1603	. . . . . .	8°	45′	„
1618	. . . . . .	8	0	„
1630	. . . . . .	4	30	„
1640	. . . . . .	3	0	„
1659	. . . . . .	2	0	
1664	. . . . . .	0	40	
1667	. . . . . .	0	0	No variation.
1669	. . . . . .	0	15	Westerly.
1670	. . . . . .	1	30	„
1683	. . . . . .	3	50	„
1700	. . . . . .	7	40	„
1750	. . . . . .	17	15	„
1767	. . . . . .	19	16	„
1780	. . . . . .	20	35	„
1785	. . . . . .	22	0	„
1800	. . . . . .	22	12	„
1807	. . . .	22	34	„
1814	. . . . . .	22	54	maximum.
1819	. . . . . .	22	39	„
1824	. . . . . .	22	33	„
1829	. . . . . .	22	12 5″	„

—*Arago*

Brussels :—

1827	October	22	28	8	Westerly.
1830	End of March . .	22	25	6	„
1832	. . . . . .	22	18	0	„
1833	. . . . . .	22	13	5	„
1834	April	22	15	2	„
1835	End of March . .	22	6	2	„
1836	. . . . . .	22	7	6	„
1837	. . . . . .	22	4	1	„
1838	. . . . . .	22	3	7	„
1839	. . . . . .	21	53	6	„
1840	. . . . . .	21	46	1	„
1841	. . . . . .	21	38	2	„
1842	. . . . . .	21	35	5	„
1843	. . . . . .	21	26	2	„
1844	. . . . . .	21	17	4	„
1845	. . . . . .	21	11	6	„
1846	. . . . . .	21	41	7	„
1847	. . . . . .	20	56	8	„

Years.	Variations.	
1848	20° 49′ 2″	„
1849	20 39 2	„

The declination has thus diminished 2° since 1827.

—*Quetelet.*

The westerly variation of the needle at the observatory at Paris, on the 30th November, 1849, 1 h. 25 m., was 20° 34′ 18″. The needle began to have a westerly variation in London from 1662. Between 1657 and 1662 the needle pointed due N. and S. at Paris, notwithstanding the small distance between the two capitals; the variation was easterly till 1669, when the needle pointed due N. and S.; since this time the variation has been westerly; it reached its maximum westerly variation about the year 1819, since which time it has been retrograding, and is now moving eastward at the rate (according to Dr. Lloyd) of about 5′ annually: the period of the westerly movement is thus about 160 years, and the limit of the angular variation about 24° 27′. At the present time the whole of Europe, with the exception of a small part of Russia, has a W. declination. In Eastern Russia, to the E. of the mouth of the Volga of Saralow, Nishni-Nowgorod, and Archangel, the easterly declination of Asia, is advancing towards us. There are particular parts of the earth's surface, as in the western part of the Antilles, and in Spitzbergen, where the mean declination of the needle has scarcely undergone any sensible change in the course of the last hundred years. Since 1660, the compass has been permanent in Jamaica. "The whole mass of West India property," remarks Sir J. Herschel,* "has been saved from the bottomless pit of endless litigation, by the invariability of the magnetic declination in Jamaica and the surrounding Archipelago, during the whole of the last century all surveys of property there having been conducted solely by the compass.

(899) The variation of the magnetic force, when viewed generally in its operation over the whole globe, does not present the character of an oscillation round a mean value, but appears as a continuously progressive change, and has hence received the name of "*Secular Change.*" Colonel Sabine, whose unceasing labours for the last twenty-five years have thrown so much light on the intricate science of terrestrial Magnetism, has lately (May 18, 1854) presented to the Royal Society a memoir, in which he has at great length discussed the observations of the magnetic declination at the observatory of St. Helena during a period of five years; the following very brief and general abstract of this valuable paper (*Phil. Mag.*) will be read

* "Cosmos." Sabine's Translation, vol. i. p. 410.

with interest, as showing the progress made in unravelling a most obscure subject.

(900) It is possible that the Magnetism of the earth may have its periods; that the phenomena existing at one and the same epoch over the whole surface of the globe, may be identically reproduced at a subsequent epoch; and that, what has been called the *Secular Change* of each of the magnetic elements, which we perceive to be in progress at any particular point of the surface, St. Helena for example, may be part of a succession of changes which operate in a cycle, of which the duration, vast as it may be, may hereafter be found calculable; but as far as our knowledge has as yet gone, it is insufficient to justify the assumption of even approximate periodical laws of this variation of the terrestrial Magnetism, and we must continue to regard it, therefore, for the present, as a secular change of which the period or periods are unknown.

(901) The average rate at which the *Secular* change, as regards *declination*, is taking place at St. Helena, was found by taking the successive differences between the monthly means of all the hourly observations in the first and second month of their continuance; then between the second and third months; and then between the third and fourth, and so on. In this way sixty differences occurred in the five years of hourly observation, by which it was found that the monthly increase of W. declination, during five years amounted on the average to 0.657m., or to an annual increase of 7·88m. A comparison of eight years, gave an average monthly increase of monthly declination of 0·661m., equal to an annual increase of 7·93m. in a solar year. During these eight years, therefore, the horizontal magnetic direction had changed at St. Helena rather more than *one* degree. By comparing eleven of the best determinations of the *declination*, all made at the same spot (the anchorage at St. Helena) by various trustworthy observers from 1610 to 1846, a period of 236 years, the rate of annual increase was found to be 8·05m. and this affords a striking example of the magnitude and character of the change wrought at a particular station, by this very remarkable feature of the earth's magnetic force. In less than *two centuries and a half* the horizontal direction which a magnet takes at St. Helena, by virtue of the terrestrial magnetic force, has been found to have changed more than 30° or more than a *twelfth part of the whole circle*, and this by a steady, equable, and uniform progression throughout the whole period.

(902) The St. Helena observations further show, that the average annual change takes place by certain aliquot portions in each month of the year, and the same features of regularity and uniformity are manifested by comparing together the fortnightly means; the whole

showing the magnitude, the regularity, and the systematic character of the changes, called *Secular*, which are thus produced by forces which are in constant operation at the surface of our planet. In our entire inability to connect these changes with any other of the phenomena of nature, either cosmical or terrestrial, we appear to have no other alternative, than to view them as a constituent feature of the terrestrial magnetic force itself, and as one of its most remarkable characteristics, not to be overlooked by those who would seek to explain the phenomena of that force by means of a physical theory. The attempts which have sometimes been made to explain them by a supposed connexion of the terrestrial magnetic phenomena with the distribution of heat on that surface, or by electrical currents excited by the rotation of the earth on its axis, contain no provision to meet a systematic variation of this nature, and break down altogether when the facts of the secular change are duly apprehended. The phenomena must find a place in any physical theory, which professes to explain the phenomena of the earth's Magnetism. It is indispensable towards the acquisition of a knowledge of the laws of terrestrial Magnetism that the complex phenomena of the secular magnetic change, should be traced out; (and this can only be done by collecting observations similar to those made at St. Helena, at a great number of stations distributed over the earth's surface), and that these should be studied separately and together; in this way order will doubtless be recognized amidst apparent irregularity, and system amidst incessant variation.

(903) By a comparison of the *isogonic* lines (lines of equal magnetic declination), corresponding to different epochs, we perceive that a secular change of the declination, almost identical with that of St. Helena, has prevailed at the same time over the greater part of the Southern Atlantic; and that from the form of the isogonic lines in that quarter of the globe (which has undergone very little variation in the last 200 years), the regularity of its progression, and its persistence in the same direction, is in accordance with that general progressive motion from E. to W., which Magneticians have long since recognized as distinguishing the general systematic change in the southern hemisphere from that in the northern, which takes place in the opposite direction; whilst from the form of the isogonic lines in that quarter we may further anticipate that at St. Helena the secular change in the *declination* will continue to take place in the same direction as at present until a line drawn through the conical summits of the isogonic curves shall in its western progress pass the geographical meridian of that station.

(904) *Periodic Variations.*—The horizontal needle is subject to

annual variations, depending on the position of the sun in reference to the equinoctial and solstitial points, and to *horary* variations corresponding to changes of temperature from the diurnal rotation of the earth.

Between the months of January and April, the magnetic needle recedes from the N. pole of the globe, so that its western declination increases.

From April to the beginning of July, that is, from the vernal equinox to the summer solstice, the declination diminishes, or the needle approaches the N. pole of the globe.

From the summer solstice to the vernal equinox, the needle receding from the N. pole, returns to the W., so that in October it has nearly the same position as in May; and between October and March, the western motion is smaller than in the three preceding months. Hence it follows that during the three months between the vernal equinox and the summer solstice, the needle retrogrades towards E.; and during the following *nine* months its general motion is towards W.

(905) There is also a daily change in the variation of the needle; this was first observed in 1724, by Mr. Graham, and has been confirmed with the most accurate instruments in almost every part of the world. When it was first discovered, the needle was supposed to have only two changes in its movements during the day. About 7 A.M. its N. end began to deviate to the W.; and about 2 P.M. it reached its maximum westerly deviation; it then returned eastward to its first position, and remained stationary till it again resumed its westerly course in the following morning. It was afterwards found that the diurnal motion commences much earlier than 7 A.M., but its motion is E. At 7½ A.M. it reaches its greatest easterly deviation, and then begins its movement W. till 2 P.M. It then returns to the eastward till evening, when it has again a slight westerly motion; and in the course of the night, or early in the morning, it reaches the point from which it set out twenty-four hours before.

(906) The following are the general results of a series of observations taken every two hours, day and night, for between two and three years, at the Dublin Observatory, under Professor Lloyd (*Brit. Assoc. Rep.*, 1843). The mean daily curve of the changes of declination for the entire year exhibits a small easterly movement of the N. end of the magnet during the morning hours, which reaches its maximum about 7 A.M.; after that hour the N. end moves rapidly westward, and reaches its extreme westerly position at 1h. 10m. P.M. It then returns to the eastward, but less rapidly, the easterly deviation becoming a maximum about 10 P.M.; the mean daily range

being equal to 9·8m. During the summer months the morning maximum at 7 A.M. is more marked; the evening maximum, on the contrary, disappears, there being a slow and regular movement of the N. end to the eastward from 7 P.M. until 7 A.M. In winter, on the other hand, the evening maximum is well defined, and the morning maximum disappears, there being a slow and regular westerly movement until 9 A.M., after which, the movement becomes more rapid in the same direction. The epoch of the extreme westerly position of the magnet is nearly the same throughout the year; the greatest daily range in summer is about 13·7m.; the least range in winter about 7·2m.

At Paris, the needle is nearly stationary during the night. At sunrise its N. extremity moves westward, as if it were avoiding the solar influence. Towards noon, or more generally from noon to 3 P.M., it attains its maximum westerly deviation, and then it returns eastward till 9, 10, or 11, P.M.; having reached its original position, it remains stationary during the night. The amount of this daily variation is, for April, May, June, July, August, and September, from 13m. to 15m.; and for the other six months of the year, from 8m. to 10m.: on some days it rises to 25m., and on others it does not exceed 5m. or 6m.

(907) Colonel Sabine has arranged and presented together (*Phil. Trans.*, 1851) the annual variations which the declination undergoes at every hour of the day at the four colonial observatories established by the British Government; at Toronto, from three years' observation; Hobarton, from five years' observation; at the Cape of Good Hope, from five years' observation; and St. Helena from three years' observation. The range of variation at all the four stations is considerably greater during the hours of the day than during those of the night, and a great similarity, though not a perfect identity, is observed at all the stations in the relative amount of the range at different hours. It further appears, that the amount does not progressively enlarge to a maximum at or about noon when the sun's altitude is greatest, or at the early hours of the afternoon when the temperature is greatest, but that at all the stations the increase of the range is most rapid in the first or second hour after sunrise, and that its extent at the hours from 7 to 9 A.M. is not exceeded at any subsequent hour at Hobarton, the Cape, and St. Helena, whilst at Toronto the great enlargement takes place even earlier, the hours of 6, 7, and 8 A.M. being exceeded by none, though they are equalled by a second increase at noon and the two following hours. The second enlargement is perceptible at the same hour at Hobarton and St. Helena.

(908) It was also observed with reference to the relative positions of the several months, at the different hours, that certain months which are found congregated at one extremity of the range during the early hours of the morning, undergo a transfer towards the opposite extremity at a subsequent period of the day. Thus, the months June, July, August, wholly occupy one extremity of the range, and November, December, January, the other extremity in the morning hours, and until from 8 to 10 A.M., when each of the two groups is respectively transferred towards the opposite extremity to that which it previously occupied. The period at which this transfer takes place is somewhat earlier at Toronto and St. Helena than at the Cape of Good Hope or Hobarton. The comportment of the two equinoctial months, March and September, at the Cape of Good Hope and St. Helena, presents a remarkable contrast to that of the two solstitial groups that have been described, and at the same time a still more remarkable contrast to each other; March being at almost all the hours on the W., and September on the E. of the mean time.

(909) Colonel Sabine returns to this most curious subject in his last memoir (*Phil. Trans.*, 1854) while discussing the annual variation at each of the hours at the observatory at St. Helena. Taking the hour of 7 A.M., the order and succession of the several months are as follows: in April, the mean declination is about ½ a minute E. of the mean declination in the year; in May, about 2′ E; in June, about 2½′ E.; in July and August, when the sequence is slightly irregular, respectively 2′ 1″ and 2′ 6″ E.; in September, the declination is again approaching the mean line, being less than 1½′ E.; in October, it has passed the mean line, being about 1¾′ *west* of it; November, December, January, and February, are congregated near the western extremity of the annual range, whilst in March we perceive that the declination is again approaching the mean line, and in April it has passed to the east of it. We have here, then, in the successive changes in the declination in the course of the year, the general fact of the existence of an annual variation, of which, at the solar hour of 7 A.M., selected as an example, or when the sun is five hours east of the meridian, the phenomena are such as have been thus cursorily described; were there no annual variation of that hour, the different months would all have the same mean declination. The annual variation, however, differs considerably at different hours; but it is a general feature amongst them, that the months on either side of the one solstice are either congregated together towards one extremity of the annual range at the same hour, whilst the months on either side of the opposite solstice are similarly congregated at the opposite

extremity; or the months of both solstices are contemporaneously in pretty rapid transition from the one extremity to the other.

(910) By projecting in a straight line the *mean* diurnal march in the year, the two *semi-annual* groups formed by grouping together the monthly means of each period of six months separated by the equinoxes, are found to assume a peculiar figure round that line, and what is particularly interesting and remarkable, the figure is so nearly the same at Toronto and Hobarton, that there can be no doubt that they all represent substantially the same phenomenon. During the hours when the sun is above the horizon, and the effects are greatest, the correspondence of the phenomena at the three stations is most striking, and there is no inversion of the phenomena in the opposite hemispheres, in both, as well as at St. Helena, in the tropics, the declination is easterly of the mean in the forenoon, and westerly in the afternoon, when the sun is N. of the equator, and reverse when he is S. The effects are the same at the three stations, though in the one hemisphere the sun being N. of the equator corresponds to summer, and in the other hemisphere to winter. There can be no doubt that this annual variation is attributable primarily to the earth's revolution round the sun in a period of the same duration, and in an orbit inclined to the equator. The similarity of effect amounting almost, indeed, to identity, at the hours when the sun is above the horizon at the station, taking place at stations where both the climatic and the terrestrial magnetic conditions are so dissimilar, seems, (observes Sabine) to remove it altogether from those physical connexions which have so often and in so many various ways, been referred to as affording possible explanations of the magnetic variations. It is evident that the epochs of the sun's passage of the equator have a very marked influence on the phenomena, and the influence is the same, and produces similar effects, whether the station itself be N. or S. of the equator, and however diverse may be its climatic or magnetic conditions.

(911) *The Inclination of the Needle.*—The dip of the needle, like the variation, undergoes a continual change, increasiug in some parts of the world, and diminishing in others. The following tables show the changes of the dip at London, since 1720; at Paris, from 1671 to 1829; and at Brussels, from 1827 to 1849.

London:—

Year.	Observed.	Observer.	Computed.
1720	74°42′	Graham	76°27′
1773	72 19	Heberden	73 40
1780	72 8	Gilpin	73 18

Year.	Observed.	Observer.	Computed.
1790	71°53′	Gilpin	72°39′
1800	70 35	ditto	71 58
1810			71 15
1818	70 34	Kater.	70 34
1821	70 3	Sabine	
1828	69 47	ditto	69 43
1830	69 38	ditto	
1833			69 21

Paris :—

Year.	Dip.	Year.	Dip.
1671	75° 0′	1818	68°35′
1754	72 15	1819	68 25
1776	72 25	1820	68 20
1780	71 48	1821	68 14
1791	70 52	1822	68 11
1798	69 51	1823	68 8
1806	69 12	1824	68 7
1810	68 50	1825	68 0
1814	68 36	1826	68 0
1816	68 40	1829	67 41
1817	68 38		

—*Arago.*

Brussels :—

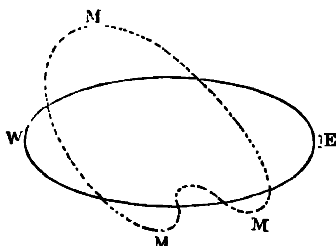
Year	Dip
1827	68° 56′ 5″
1830	68 51 7
1832	68 49 1
1833	68 42 8
1834	69 38 4
1835	68 35 0
1836	68 32 2
1837	68 28 8
1838	68 26 1
1839	68 22 4
1840	68 21 4
1841	68 16 2
1842	68 15 4
1843	68 10 9
1844	68 9 2
1845	68 6 3
1846	68 3 4
1847	68 1 9
1848	68 0 4
1849	67 56 8

—*Quetelet*

The magnetic dip reached its maximum in London, in 1720, it being then 74° 42′; it is now, according to observations made at Greenwich, about 68° 30′, so that, during the last 134 years, it has lost 6° 12′, being at the rate of nearly 3′ each year. The horary variation of the dip is small; according to Hansteen, it is 4′ greater in the morning than in the afternoon. At Toronto, the inclination on 1st March, 1847, was 75° 16′ ·09 with an annual increase of 0′ 89. —(*Sabine.*)

(912) *The Magnetic Equator.*—This is an irregular line crossing the terrestrial equator at *four* points, as shown in Fig. (306) where the black line W E, may be supposed to represent the real equator, and the dotted line M M M, the magnetic equator, crossing the former at *four* points instead of two, and showing the evident existence of some great disturbing cause.

Fig. 306.



(913) MM. Morlet and Hansteen have determined the true form of the magnetic equator with great care; they have traced it over the whole globe, and have found that its motion is from E. to W. in so far as can be determined by direct observations on the position of its nodes. They both place the magnetic equator wholly to the S. of the terrestrial equator, between Africa and America; its greatest southern latitude being at 25°. One node is in Africa, in about 22° of E. longitude, or in 18° according to Morlet. In setting out towards the E. from this node, which is nearly in the centre of that part of the African continent, the magnetic equator advances rapidly to the N. of the terrestrial equator, quits Africa a little to the S. of Cape Guardafui, and in the Arabian Sea it attains its most northerly latitude of about 12°, in 62° of E. longitude; between this meridian and 174° E. the magnetic equator is constantly to the N. of the equinoctial line. It cuts the Indian Peninsula a little to the N. of Cape Cormorin, traverses the Gulf of Bengal, making a slight advance to the equinoctial, from which it is only 8° distant at the entry of the Gulf of Siam. It then reascends a little to the N. almost touches the N. point of Borneo, traverses the Isle of Paragua, the strait which separates the most southern of the Philippines from the Isle of Mindanao, and under the meridian of Naigiou, it again reaches .the N. latitude of 9°. From this point it traverses the Archipelago of the Caroline Islands, and descends rapidly to the equinoctial line, which it cuts, according to Morlet in 174°, and according to Hansteen in 187° E. longitude.

There is much less uncertainty respecting the position of a second node, also situated in the Pacific Ocean. Its W. longitude ought to be about 120° ; but while M. Morlet's inquiries lead him to conclude that the magnetic equator merely touches the equinoctial at that point, and then bends again to the south, M. Hansteen makes it cross the line into the northern hemisphere, and continue there through an extent of 15° of longitude, and then return southward, and cross the equinoctial again in about 108° of W. longitude, or 23° from the W. coast of America. This discrepancy between the results of Morlet and Hansteen is, after all, very trivial; for in the case just mentioned, the magnetic equator does not go more than 1½° to the equinoctial; and in general the magnetic equator of Morlet differs in no part so much at 2° in latitude from that of Hansteen.

(914) The observations of Captain Duperrey, made on board the Coquille, in the years 1822-25, have contributed considerably to our stock of knowledge on the subject of terrestrial Magnetism, and particularly on the form and motion of the magnetic equator. This vessel crossed the magnetic meridian six times, and M. Duperrey was enabled to determine directly two of its points, situated in the Atlantic Ocean. On the chart of Morlet, and in that of Hansteen, the latitudes of those parts, which correspond to the same longitudes, are greater by 1° 43′ and 1° 50′; and hence M. Arago has concluded that the magnetic equator has approached the terrestrial equator by the same quantities. In the South Sea, near the coast of America, Duperrey has determined two points of the magnetic equator. On the charts of Morlet and Hansteen, the latitudes of these points are about a degree smaller, but the difference is in a direction contrary to that which was found in the Atlantic Ocean; from which it follows, that near the coast of Peru, the magnetic equator has removed from the equinoctial line.

(915) In a chart of the equatorial regions, which M. Duperrey has drawn up and published in the *Annales de Chimie*, for 1830, these results are laid down: "That the magnetic equator will meet the equinoctial line only in two points, which are diametrically opposite, the one situated in the Atlantic Ocean, and the other in the great ocean, nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line; when the islands are more numerous, it recedes farther; and it reaches its maximum deviation in both hemispheres, only in the two great continents which it traverses. He found also, that between the northern and southern halves of the

magnetic equator, there is a symmetry very remarkable, and much more perfect than had previously been believed.

"The dip of the needle increases on each side of the magnetic equator; and Hansteen has projected lines of equal dip in his chart. These lines are nearly parallel to the magnetic equator, till we reach 60° of N. latitude; they then begin to bend round the American magnetic pole which Sir James Clark Ross found to be situated in N. latitude 70° 5′ 17″, and W. longitude 96° 45′ 48″, the needle having at this point in Boothia Felix lost wholly its directive power, and the dip being 89° 59′ within *one* minute of 90° or vertical. Had we inferred the position of the needle from the form of the magnetic equator, we should have placed it in 25° of W. longitude, viz., the meridian on which the magnetic equator advances farthest to the S., or about 13½°, and 76½° of N. latitude, or 90°—13½°. This, however, as all arctic observations prove, is not the case, and we are led by the phenomena of the dip, as well as by those of the variation in different parts of the globe, to conclude that every place has its own magnetic axis, with its own pole, and its own equator, as stated by Mr. Barlow."

(916) *Terrestrial Magnetic Intensity.* — It has become a most important practical problem, connected with the physical condition of the globe, to determine the intensity of its Magnetism at different points on its surface, and the changes which it undergoes at different seasons of the year, and at different times of the day.

Mr. Graham first suggested a method of determining this, by the number of oscillations of the magnetic needle; and this plan has been since much improved by Coulomb, Humboldt, and others.

If a needle, whose axis of suspension passes through its centre of gravity, and which has its N. and S. polar Magnetism equal and similarly distributed, be made to vibrate, by turning it from its position, and allowing it to recover that position by a series of oscillations, it is evident that the Magnetism of the earth will act with equal force on each half, and that the needle will be drawn into the magnetic meridian by the combined action of both forces. The greater the magnetic force, the more quickly will the needle oscillate, and recover its primitive position. The needle is, in short, in the same circumstances as a pendulum, oscillating by the action of gravity; and as in this case, the forces are as the squares of the number of oscillations made in the same time.

Suppose the dipping needle be made to oscillate in the plane of the magnetic meridian, round the line of the dip, and that when an experiment is made at the equator, the number of oscillations in a second is 24, while in another place it is 25; then the intensity of

the magnetic force at these places, is as 25^2 to 24^2, or as 625 to 576, or as 1·085 to 1·000. By carrying the same needle to different parts of the earth, the magnetic intensity at these places will be found from the number of its oscillations.

(917) In the application of this method there are various practical difficulties, particularly the necessity of the needle resting on knobs, edges of steel, or agate, during its oscillations; these difficulties are avoided by suspending it by a fibre of silk, and allowing it to oscillate horizontally. This method is therefore the one adopted, though a little calculation is necessary to obtain the intensity of terrestrial Magnetism, from the number of oscillations that are performed.*

Hansteen has drawn up a table, which is too long for insertion here, exhibiting the magnetic intensity in almost every part of the world, from observations made principally by himself and his friends. He has projected, on a map of the globe, the lines passing through all the places in which the intensity has the same value. These lines he calls *isodynamic lines*, or those of equal force; and they are, generally speaking, nearly parallel to each other, and to the lines of equal dip.

(918) The same indefatigable philosopher, not satisfied with the many valuable observations which were made during the various arctic expeditions which were sent out by the British government, and being exceedingly anxious to establish, by direct observations of his own, the existence of the secondary magnetic pole, which he believed existed in Siberia, undertook a journey at the expense of the Norwegian Storthing, and with every encouragement and assistance from the Russian government. The results of his expedition were highly satisfactory; and in consequence, the Russian Academy of Sciences were induced to take a new interest in the subject of terrestrial Magnetism, which exhibits such important features throughout the Russian empire; and the Russian government has established regular observatories in various parts of its vast dominions for making magnetic experiments. The Russian empire is actually traversed by *two* lines of no variation, and it is proposed to determine with great precision, every ten years, the exact position of these two lines. Near the first of them, which traverses European Russia, Petersburg, Moscow, and Cazan are situated; and near the second, which passes through Siberia, are situated Kiachta and Nizni Oudinsk. Observations are yet wanting to determine in what manner the inten-

* See Harris's Magnetometer of Oscillation, *Edin. Phil. Trans.*, vol. xiii. part I. Trans. Roy. Soc., 1831.

sity varies with the height. Humboldt is of opinion that it decreases, confirming the deductions of Kupffer.

By combining all the observations of intensity from 179° to 183°, M. Hansteen has drawn the conclusion, *that the total magnetic intensity is smaller in the southern than in the northern hemisphere.* M. Duperrey has confirmed this result.

(919) The magnetic intensity, like the variation and dip of the needle, undergoes monthly and diurnal changes. Hansteen found by means of the vibrations of a needle delicately suspended, that the *minimum* of daily change of intensity is between 10 and 11 A.M., and the *maximum* between 4 and 7 P.M. in May, and about 7 P.M. in June. The intensity is a maximum in December, and a minimum in June. The greatest monthly change in the intensity is a maximum in the months of December and June, about the time when the earth is in its perihelion and aphelion. It is a minimum near the equinoxes, or when the earth is at its mean distance from the sun. The greatest daily change is least in the winter, and greatest in the summer. The greatest difference of the annual intensity is 0·0359. M. Hansteen likewise found that the magnetic intensity is diminishing in Europe, and that the decrease is greater in the northern and eastern, than in the southern and western parts—an effect which he conceives to be produced by the motion of the Siberian pole towards the E. At Port Bowen, Captain Parry observed an augmentation of the magnetic intensity to take place from the morning till the afternoon, and a diminution of it from the afternoon till the morning. These results of M. Hansteen have been confirmed by Mr. Christie,* who has shown that the terrestrial magnetic intensity is a minimum between 10 and 11 A.M.; the time nearly when the sun is in the magnetic meridian; that it increases from this time until between 9 and 10 A.M., after which it decreases, and continues decreasing during the morning, till it reaches its minimum between 10 and 11 A.M. These results were deduced from observations made in May, *within doors,* to determine the positions of the points of equilibrium at which a magnetic needle was retained, at different hours during the day, by the joint action of two bar magnets, and by terrestrial Magnetism, reduced to their true positions at the standard temperature 60° of the magnet.

Mr. Christie repeated his observations *in the open air* in June, and from these it appears that the minimum intensity happened nearly at the time the sun passed the magnetic meridian, and rather later than in May, which was also the case with the time of the sun's passage

* *Philosophical Transactions,* 1825, pp. 49—51.

over the meridian. The intensity increased till about six o'clock in the afternoon, after which it appears to have decreased during the evening. The following table shows the results of the observations of Mr. Christie, compared with those of M. Hansteen:—

Intensity deduced from Hansteen's Observations in 1820.			Intensity deduced from Mr. Christie's Observations in 1823.		
TIME.	MAY.	JUNE.	TIME.	MAY.	JUNE.
8 h 0m. A.M.	1·00034	1·00010	7 h 30m.	1·00114	1·00061
10 30	1·00000	1·00000	10 30	1·00000	1·00000
4 0 P.M.	1·00299	1·00251	4 30	1·00175	1·00223
7 0	1·00294	1·00304	7 30	1·00220	1·00339
10 30	1·00191	1·00267	9 30	1·00231	1·00209

The principal difference between these results is, that in Mr. Christie's observations the intensity seems to diminish more rapidly in the morning, and increase more slowly in the afternoon, than it does in those of Hansteen.

(920) The philosopher who has contributed more largely than any other to our knowledge of the magnetic intensity and its laws, is Colonel Sabine, who, since the year 1819, has made this a subject of unceasing study. It appears that there are two foci or points of maximum force in each hemisphere round which the isodynamic lines circulate in an ovate form; these foci are not of equal force in either hemisphere: the focus of greater intensity in the northern hemisphere is in North America, in the vicinity of the S.W. shores of Hudson's Bay in 52° of latitude; the weaker focus is in the North of Siberia, about 120° of E. longitude from Greenwich. The corresponding phenomena of the southern hemisphere are not yet determined with an equal precision. The two major foci, one in the northern and the other in the southern, are not at opposite points of the globe to each other, neither are the two minor foci. At both the foci of the northern hemisphere the predominance is of the forces which attract the N. end of the needle and repel the S., and at both the foci of the southern hemisphere the converse is the case. The ratio of the magnetic force at the major focus in North America as determined by Captain Lefroy, is 13·9; at the minor focus in Siberia from the observations of Hansteen and Duc, 13·3; at St. Helena, which is at the weakest part of the line of least intensity, its value is 6·4. The approximate value of the force of the major focus in the southern hemisphere is 15·6; that of the minor about 14·9. The unit of force in this scale is that amount of magnetic force which acting on the unit of mass through the unit of time, generates in it the unit of

velocity, and the units are taken respectively as a grain, a second, and a foot in British measure. ("Cosmos," note by Colonel Sabine, vol. i., p. 416.) According to Sabine's observations at Toronto, the horizontal force from January to April, 1845, possessed there a mean value of 3·53043, with a mean annual decrease of 0·0042. At Toronto and at Hobart Town (Van Dieman's Land), two magnetic stations which are nearly at opposite points of the earth's surface, the total magnetic force from October to April inclusive, is greater than from April to August inclusive, and the inclination needle in both places stands more nearly perpendicular during the former period than during the latter.

(921) From Lloyd's observations at the magnetic observatory at Dublin, it appears that the mean daily course of the horizontal force for the entire year has two maxima and two minima. The first minimum occurs between 1 A.M. and 3 A.M., or a little after. These fluctuations are small. A second and principal minimum takes place at 10h. 10m. A.M., and a second and principal maximum about 6 P.M., the mean daily course being ·0024 of the whole intensity. In the smaller months, the smaller maximum and minimum disappear, the intensity decreasing continually throughout the night, but slowly till 5 or 6 A.M., after which the decrease becomes rapid. There is consequently but one maximum and one minimum in the mean daily curve, which nearly correspond in epoch with the principal maximum and minimum of the curve for the entire year. In the winter months, on the other hand, there are three maxima and three minima, the evening maximum appearing to break into two. The epoch of the morning maximum moves forward as the line approaches the winter solstice, appearing to depend upon the hour of sunrise, which it precedes by a short interval. The epoch of the principal minimum is nearly constant throughout the year. The daily range is greatest in the month of July, when it is about ·0045 of the whole intensity; it is least in the month of January, being then about ·0008 of the whole. The total intensity appears to vary very little throughout the day: it seems to be least about 9 A.M., and then to increase, attaining a double maximum in the afternoon; the total range is, however, very small. From a review of the facts, Professor Lloyd concludes that the diurnal changes in the direction of the magnetic force are connected with the diurnal movement of the sun, and its times of rising and setting; but that the changes of the intensity appear to be influenced, in addition, by some other cause.

(922) *Magnetic Storms.*—This term was applied by Humboldt to certain fitful agitations of the needle, which he was the first to notice, at Berlin, in 1806. The phenomenon has since engaged the

attention of all philosophers occupied with the subject of terrestrial Magnetism. These unaccountable commotions of the needle occur at irregular intervals, are of short duration, but of immense extent. In 1818, a magnetic storm, shown by a violent agitation of the needle, took place simultaneously over 47° of longitude, extending through all the countries from Paris to Cazan; and on the 25th of September, 1841, one of these storms was simultaneously observed at Toronto, in North America, at the Cape of Good Hope, Prague, in Europe, and Macao, in China; and there is reason to believe that it extended to Van Diemen's Land. Similar storms have happened simultaneously in Sicily, and at Upsala, in Sweden (Mrs. Somerville's "Physical Geography.") "When the ordinary horary movement of the needle," says Humboldt (*Cosmos*), "is interrupted by a magnetic storm, the perturbation manifests itself often simultaneously, in the strictest sense of the word, over land and sea, over hundreds and thousands of miles, or propagates itself gradually, in short intervals of time, in every direction over the surface of the earth." When this sudden interruption or disturbance of the horary movement of the needle announces the presence of a magnetic storm, we are unable to determine the seat of the perturbing cause, whether it be in the crust of the earth or in the upper regions of the atmosphere, nor are we able to attribute it to any known cause. The aurora is now, on all hands, recognized as a magnetic phenomenon; its appearance is foretold by an irregularity in the diurnal march of the needle, indicating a disturbance in the equilibrium of the distribution of the earth's Magnetism. "When the disturbance has reached a great degree of intensity the equilibrium is restored by a discharge, accompanied by an evolution of light. The aurora is not, therefore, to be itself regarded as a cause of the perturbation, but as a result of a state of stellaric activity excited to the production of luminous phenomena: an activity which manifests itself, on the one hand, by the fluctuations of the needle, and on the other, by the appearance of the brilliant auroral light. The magnificent phenomenon of coloured polar light is the act of discharge—the termination of a magnetic storm." (*Cosmos.*)

(923) The magnetic character of the aurora is clearly shown by Sabine in his "Observations on Days of unusual Magnetic Disturbance made at the British Colonial Magnetic Observatories." On examining the meteorological registers at the Toronto observatory, with reference to the appearance of these meteors, on the twenty-four days of principal magnetic disturbance at that station, it was found that on thirteen days of the twenty-four, the aurora was visible, and that on the remaining eleven days the sky was either

densely overcast, or heavily-clouded, so that the aurora, though it might exist, could not be seen. It is to be observed, however, that the days on which magnetic disturbance and auroræ occurred together at Toronto, were days of disturbance also at Prague and Van Diemen's Land; so that we may view the occurrence of auroræ at Toronto on these occasions as local manifestations connected with magnetic effect, which, whatever may have been their origin, probably prevailed on the same day over the whole surface of the globe.

(924) *Theory of Terrestrial Magnetism.*—Little that is satisfactory can be said on this head. Actively as the study of terrestrial magnetic phenomena is now proceeding, much remains to be done, before anything approaching to a solution of its wondrous and complex phenomena can be hoped for. It may not, however, be amiss to conclude this portion of our subject with a brief notice of the speculations of Hansteen, and of Mr. Barlow's experimental application of the electro-magnetic hypothesis, first advanced by Sir David Brewster.

(925) The Magnetism of the earth cannot be explained by the action of two magnetic poles at a distance from each other; on the contrary, Biot has observed, that the nearer the poles were taken to each other, the greater was the agreement between the computed and the observed result.

"For these reasons," says Hansteen (in his work on the Magnetism of the earth) "it appears most natural to seek their origin in the sun, the source of all living activity; and our conjecture gains probability from the preceding remarks on the daily oscillations of the needle. Upon this principle the sun may be conceived as possessing one or more magnetic axes, which by distributing the force, occasion a magnetic difference in the earth, in the moon, and in all those planets whose internal structure admits of such a difference. Yet allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance; for the question may still be asked with equal justice, *whence did the sun acquire its magnetic force?* And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the Milky Way for its equator, we but lengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point of support. All things considered, the following mode of considering the subject seems to me the most plausible. If a single globe were left alone to move freely in the immensity of space, the opposite forces existing in its material structure would soon arrive at an equilibrium conformable to their nature, if they were not so at first, and all activity would soon come to an end. But

if we imagine another globe to be introduced, a mutual relation will arise between the two; and one of its results will be a reciprocal tendency to unite, which is designated and sometimes thought to be explained, by the merely descriptive word *attraction*. Now, would this tendency be the only consequence of that relation? Is it not more likely that the fundamental forces, being driven from their state of indifference or rest, would exhibit their energy in all possible directions, giving rise to all kinds of contrary action? The electric force is excited not by friction alone, but also by contact, and probably also, although in smaller degrees, by the mutual action of two bodies at a distance; for contact is nothing but the smallest possible distance, and that moreover only for a few small particles. Is it not conceivable that magnetic force may likewise originate in a similar manner? When the natural philosopher and the mathematician pay regard to no other effect of the reciprocal relation between two bodies at a distance, except the tendency to unite, they proceed logically, if their investigations require nothing more than a moving power; but should it be maintained that no other energy *can* be developed between two such bodies, the assertion will need proof, and the proof will be hard to find.

"I reckon it possible, therefore, that by means of the mutual relation subsisting between the sun and all the planets, as well as between the latter and their satellites, a magnetic action may be excited in every one of those globes, whose material structure admits of it, in a direction depending on the position of the rotatory axis with regard to the plane of the orbit. Each of the planets may thus give rise to a particular magnetic axis in the sun; but as their orbits make only small angles with the sun's equator and each other, these magnetic axes would perhaps, on the whole, correspond with the several rotatory axes. Such planets as have no moons, would, on this principle, have but one magnetic axis; the rest would in all cases have one axis more than they have moons, if those different axes, by reason of the small angles which the orbits of their several moons form with each other, did not combine into a single axis. The conical motions by which the rotatory axes of the planets are carried round the pole of the ecliptic (the precession in the earth), joined to the revolving motion of the orbits about the sun's equator (which occasions the present diminution in the obliquity of the ecliptic), might perhaps, in this case, account for the change of position in the magnetic axis. It would greatly strengthen this hypothesis, if the above great magnetic period, after the lapse of which both axes again assume the same position, should in fact be found to coincide with the period of the precession, which, however, seems a little doubtful."

(926) Such were the speculations of Hansteen. But Sir David

Brewster has proved, from an immense number of meteorological observations, that there were in our northern hemisphere two poles of maximum cold; that these poles coincided with the magnetic poles; that the circle of maximum heat, like the magnetic equator, did not coincide with the equinoctial line; that the isothermal lines, and that the lines of equal magnetic intensity, had the same general form, surrounding and enclosing the magnetic poles and those of maximum cold; and that by the same formula, *mutatis mutandis*, we could calculate the temperature and the magnetic intensity of any point of the globe; thus there can be no doubt that there is a close connexion between the phenomena of temperature and Magnetism; and since the discovery of Dr. Seebeck, that the mere application of heat to a circuit of two metals is capable of developing magnetic effects, we may consider that we have arrived a step nearer to an explanation of the earth's Magnetism, by referring to the sun as the great agent of all these phenomena; but we have yet to discover the metallic thermo-magnetic apparatus by which they are produced.

(927) The electro-magnetic hypothesis was first advanced by Sir David Brewster; and Mr. Barlow has, by a beautiful experiment, shown its application. It occurred to him that if he could distribute over the surface of an artificial globe a series of galvanic currents, in such a way that their tangential power should everywhere give a corresponding direction to the needle, this globe would exhibit, while under electrical induction, all the magnetic phenomena of the earth upon a needle freely suspended above it. The following is an account of the experiment:—

"I procured a wooden globe, 16 inches in diameter, which was made hollow for the purpose of reducing its weight, and while still in the lathe, grooves were cut to represent an equator and parallels of latitude, at every $4\frac{1}{2}°$ each way from the equator to the poles; these grooves were about $\frac{1}{8}$th of an inch deep and broad; and, lastly, a groove of the same breadth, but of double the depth, was cut like a meridian from pole to pole half round. These grooves were for the purpose of laying in the wire, which was effected thus: the middle of a copper wire nearly 90 feet long, and $\frac{1}{10}$th of an inch in diameter, was applied to the equatorial groove, so as to meet in the transverse meridian; it was then made to pass round this parallel, returned again along the meridian to the next parallel, and then passed round this again, and so on, till the wire was thus led in continuation from pole to pole.

"The length of wire still remaining at each pole was bound with varnished silk, to prevent contact, and then returned from each pole along the meridian groove to the equator. At this point, each wire

being fastened down with small staples, the wires for the remaining 5 feet were bound together to near their common extremity, where they opened to form two points for connecting the poles of a powerful compound voltaic battery.

"When this connexion was made the wire became, of course, an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction; and consequently, agreeably to the laws of action above described, a neutralized needle freely suspended above such a globe, would arrange itself in a plane passing from pole to pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

"In order to render the experiment more strongly representative of the actual state of the earth, the globe in the state above described, was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic poles, according to the best observations we have for this determination; I therefore placed them in latitude 72° N., and 72° S., and on the meridian corresponding with 76° W., by which means the magnetic and true equators cut one another at about 14° E. and 166° W. longitude.

"The globe being thus completed, a delicate needle must be suspended above it, neutralized from the effect of the earth's Magnetism, according to the principle I employed in my observations on the daily variation, and described in the *Philosophical Transactions* for 1823; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive the globe now to be placed so as to bring London into the zenith, then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its N. end depressed about 70°, as nearly as the eye can judge, *which is the actual dip in London.* If now we turn the globe about on its support, so as to bring to the zenith places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, being first zero, and then gradually increasing eastward as happens on the earth. If again we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease, till at the equator it vanishes, the needle becoming horizontal; continuing the motion, and approaching the S. pole, the S. end of the needle will be found to dip, the degree of inclination increasing continually from the equator

to the pole, where it becomes again vertical, but reversed as regards its verticality at the N. pole."

(928) But although a sphere thus arranged may be made to exhibit the phenomena of terrestrial Magnetism without the aid of any magnetic body, we have yet to learn how such a system of electrical currents can have existence in the earth, unless we refer them to the action of the sun on a metallic thermo-electric apparatus distributed over the earth. It would still, however, remain to be shown what this thermo-electric apparatus is, and where and how it is distributed.

Whether we seek for a cause of terrestrial Magnetism in electrical currents, induced on the earth's surface, or whether we refer it to Magnetism induced on the ferruginous matter it contains, or in its atmosphere, we are limited to the *Sun*, if not as a primary cause, at least as an agent, to which magnetic phenomena have a distinct reference; future investigation must decide whether it acts by its heat, or by its light, or by specific rays, or influences of a magnetic nature.

CHAPTER XVIII.

ELECTRO-MAGNETISM.

Oersted's discovery—Affections of the needle and electrified wire—Mutual actions and reactions—De la Rive's floating ring—Mutual actions of parallel electrical currents—Laws of angular currents—Sinuous currents, solenoids—Galvanometers—Faraday's researches—Electro-magnetic rotations—Electro-magnets and electro-magnetic engines.

(929) THE disturbance produced in the magnetic needle by the aurora borealis and lightning, had long suggested to philosophers that the agencies of Electricity and Magnetism must be connected by some close and intimate relation. For nearly half a century the discovery of this relation was a favourite subject of speculation; and it is curious to compare the various opinions which were maintained by different experimentalists. Magnetic properties were easily communicated to bars of steel, by passing strong electrical shocks through them, but no general law could be traced as governing the polarity thereby imparted. D'Abilard imagined, that he had proved that the electric discharge imparts a northern polarity to that point of a steel bar at which it enters, and a southern polarity to that at which it makes its exit; and this quite independently of the position of the needle, with respect to the magnetic poles of the earth. Wilke, on the other hand, was equally satisfied that an invariable connexion exists between the negative Electricity and the northern polarity.

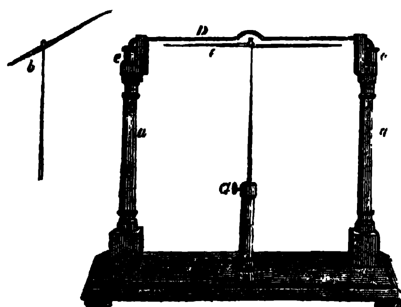
(930) In one of the essays (which received a prize) on the question proposed by the Electoral Academy of Bavaria, in 1774: "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the animal body?" Professor Van Swinden, of Franeker, after a long and elaborate discussion of the subject, arrived at the conclusion, that the similarity between Electricity and Magnetism amounts merely to an *apparent* resemblance, and does not constitute a true physical analogy; whence he infers that these two powers are essentially different and distinct from each other. On the other hand, Professors Steiglehner and Hubner, maintained that both classes of phenomena are referable to the *same* agent, varying only in consequence of a diversity of circumstances. In this unsettled state, the subject remained till some years after the discovery of Galvanism, by which a fresh field of inquiry was opened, and a means of maintaining a

large and continuous current of Electricity obtained. The first approach to a solution of the question, was the publication of Ritter; he asserted, "that a needle, composed of silver and zinc, arranged itself in the magnetic meridian, and was slightly attracted and repelled by the poles of a magnet;" he also stated, "that by placing a gold coin in the voltaic circuit, he had succeeded in giving to it positive and negative electric poles; and that the polarity so communicated, was retained by the gold, after it had been in contact with other metals, and appeared therefore to partake of the nature of Magnetism: that a gold needle, under similar circumstances, acquired still more decided magnetic properties;" and, "that a metallic wire, after being exposed to the voltaic current, took a direction N.E. and S.W."

(931) In consequence of the vague and loose manner in which Ritter advanced his speculations, but little notice was taken of them, and no satisfactory results were obtained till the year 1819, when Professor Oersted, of Copenhagen, made his famous discovery, which forms the basis of the science of Electro-magnetism. The fact observed by Oersted was, that when a magnetic needle is brought near the connecting medium (whether a metallic wire or charcoal, or even saline fluids of a closed voltaic circle), it is immediately deflected from its natural position, and takes up a new one, depending on the relative positions of the needle and wire. If the connecting medium be placed horizontally *over* the needle, that pole of the latter which is nearest to the *negative* end of the battery, always moves *westward;* if it be placed *under*, the same pole moves to the *east.* If the connecting wire be placed parallel with the needle, that is, brought into the same horizontal plane in which the needle is moving, then no motion of the needle in that plane takes place; but a tendency is exhibited in it to move in a vertical circle, the pole nearest the *negative* side of the battery being depressed, when the wire is to the *west* of it, and elevated when it is placed on the *eastern* side.

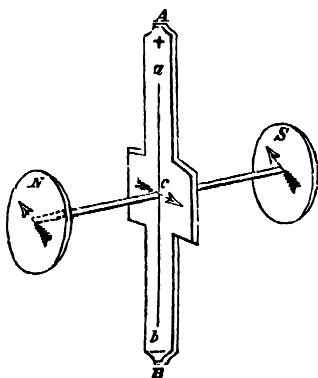
Fig. 307 represents a convenient arrangement for exhibiting the action of a wire conducting a current of Electricity on the magnetic needle. *a a*, two turned wooden pillars screwed into a base board B, and surmounted by two mercury cups *c c*. D, a copper wire, the ends of which dip into the mercury, as do also the wires connected with

Fig. 307.



the opposite extremities of a simple voltaic battery. A current of Electricity can thus be made to pass in either direction along the wire D: *e* is the magnetic needle nicely poised on a wire, which by means of the screw G may be elevated or depressed, and the needle thus set either above or below the wire D, or it may be removed and replaced by the dipping needle *b*. The needle is likewise affected when suspended over the battery itself, but its movements are the reverse of those which take place when it is suspended over the connecting wire. As in all electro-magnetic researches it is necessary to bear in mind these affections of the needle and electrified wire, several contrivances have been made to assist the memory respecting the details. Fig. 308 represents the plan of Dr. Roget. *A B* is a slip of card, on each side of which a line *a b* is drawn along the middle of its length, the end *a* being marked +, the end *b*—, and the centre *c* being crossed by an arrow, at right angles to it, directed as in the figure. Through the centre, and at right angles to the plane of the slip of card, there is made to pass a slender stem of wood, at the two ends of which are fixed in planes, parallel to the slip of card *A B*, the circular discs of cards marked respectively with the letters *N* and *S*, and with arrows parallel to, but pointing in a contrary direction to the one at *c*. The same marks must be put on the reverse of each of the three pieces of card, so that when held in different situations they may be seen without turning the instrument.

Fig. 308.



(932) If the line *a b*, be supposed to represent the connecting wire (the direction of the current of Electricity being denoted by the signs + and — at the ends of the line), the arrow at the centre will point out the direction in which it tends to move, when under the influence of the N. pole of a magnet, situated at *N;* or of a S. pole situated on the other side, as at *S;* and *vice versâ* the arrows *N* and *S*, will indicate the directions in which the N. and S. pole respectively tends to revolve round the connecting wire in its vicinity, with relation to the direction of the current of Electricity that is passing through it. It must be observed that the poles *N S* are not considered as in connexion with each other, or as forming parts of one magnet; their operations are exhibited singly and quite independently of each other. The advantage of the instrument consists in its being capable of being held in any situation, and thus easily adapted

to the circumstances of any fact or experiment of which we may wish to examine the theory.

(933) A useful help to the memory has also been suggested by Ampère. Let the observer regard himself as the conductor or connecting wire, and imagine a positive electric current to pass from his head towards his feet in a direction parallel to the magnet; then its N. pole in front of him will move to his right side, and its S. pole to his left. The plane in which the magnet moves is always parallel to the plane in which the observer supposes himself to be placed. If the plane of his chest be horizontal, the plane of the magnet's motion will be horizontal; but if he lie on either side of the horizontally suspended magnet, his face being towards it, the plane of his chest will be vertical, and the magnet will tend to move in a vertical plane. Figs. 309 and 310 represent the direction of the circulating current of Magnetism. In Fig. 309 the connecting wire is placed vertically, the electric current descending it from p to n; the arrows denote the direction in which the N. pole of a magnet will have a tendency to move round it; *i. e.* from left to right, or in the direction of the hands of a watch. Fig. 310 shows the motion impressed on the S. pole by a similar current; when the direction of the electricity is reversed, the wire still preserving its vertical position, the direction of the action is also reversed. From the manner in which the needle is affected when placed parallel to either side of the current it was inferred that a *current of Magnetism* is set in motion at right angles to the latter. This was termed by Dr. Wollaston *Vertiginous* Magnetism; and by Mr. Barlow, the magnetic force was said to exert a *tangential* action.

Fig. 309.

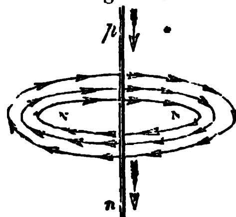
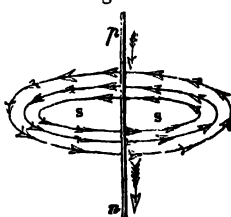


Fig. 310.

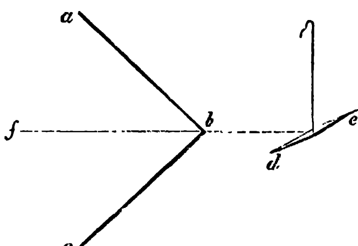


(934) The extent of the declination of the magnetic needle depends entirely on the *quantity of Electricity* passing along the connecting wire, and has nothing to do with the *tension* of that Electricity, nor is it increased by increasing the intensity of the current; hence the employment of galvanic batteries for the exhibition of the effects of Electro-magnetism: we see here also the reason why the first inquirers were foiled in their attempts to elicit these effects.

(935) The force exerted by the electric current on the magnetized needle diminishes in intensity in proportion as the distance between the current and the needle increases. The law, in accordance with which this diminution is regulated, was determined by MM. Biot and

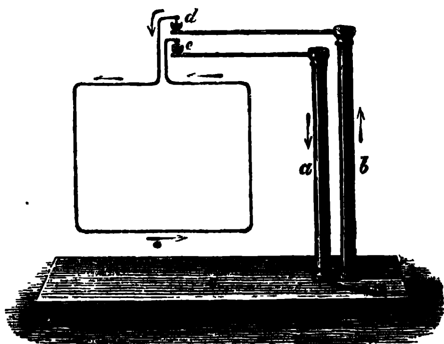
Savary. When the current is rectilinear, and the length of the wire considerable, so that in relation to that of the needle it may be regarded as infinite, the intensity of the electro-magnetic force is *in inverse ratio to the simple distance of the magnetized needle from the current.* But it is only under these conditions that the law is true, for Laplace has shown that the elementary electro-magnetic force, that is, the elementary action of a simple section of the current upon the needle, is like all other known forces in the inverse ratio of the *square of the distance*, and proportional to the sine of the angle formed by the direction of the current, and by the line drawn through the centre of the section to the centre of the needle. In fact, by calculating according to this principle, the sum of all the elementary actions that are exercised on a small needle by an indefinite rectilinear current, it is found that the intensity of this resultant should be, as experiment proves it really is, in the inverse ratio of the simple distance. From the same law of the elementary force it follows, that the intensity of the action of an indefinite angular current, *a b c*, (Fig. 311) on a small needle, *d e*, is in the inverse ratio of the distance, *b d*, like that of the rectangular current, but it is moreover proportional to the tangent of half the angle, *a b f*.

Fig. 311.



(936) The action of the electric current on the magnet is attended with a corresponding and equal reaction of the magnetic poles on the current. Fig. 312 exhibits the apparatus contrived by Ampère for showing the action of a fixed magnet on a moveable rectangular wire. Two metallic uprights, *a*, *b*, provided at their lower extremities with cups to hold mercury, are fixed on a base board, *c*; from the tops of these vertical rods proceed long horizontal arms, carrying at their ends brass mercury cups. The moveable conductor consists of a rectangular copper wire, its two extremities being brought back near each other, so that their points may dip into the mercury capsules,

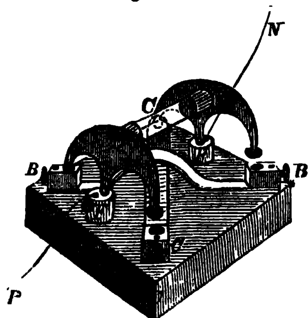
Fig. 312.



d, *e*; one of the poles of the voltaic battery is made to communicate with the lower extremity of one of the fixed conductors, and the other with the corresponding extremity of the second pillar. Supposing the connexions to be made in the manner indicated in the figure, then the current will circulate through the system in the direction pointed out by the arrows, and on placing a magnetized bar below and very near to the lower part of the wire, the latter immediately moves and sets itself transversely to the magnet. On altering the direction of the current, or on turning the fixed magnet round, the wire again moves and describes an angle of 180° in order to take up a position the reverse of that which it previously occupied, and which is in strict accordance with Ampère's formula in the case of a fixed current and moveable magnet.

(937) In making electro-magnetic experiments, it is convenient to be provided with an apparatus for reversing the direction of the electrical current without disturbing the conducting wires. Fig. 313 shows the contrivance of Magnus for this purpose.

Fig. 313.

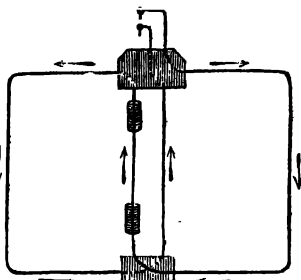


A A is a block of wood on which are fixed the two brass bands, *B B*, *C C*, terminated at their extremities by square blocks of brass with binding screws and cup-shaped holes. *D D*, two flat pieces of brass connected and insulated by the glass rod, *E*. These are the break pieces, and move on joints at *F F*, where they are connected by the wires, *P N*, with the battery. The other binding screws at the termination of the brass bands serve to connect the arrangement through which the currents are to pass.

(938) The rectangular wire when traversed by a powerful voltaic current, and when its diameter is from 18 inches to 2 feet, is acted upon sensibly by terrestrial Magnetism; it sets itself, in fact, transversely, or perpendicularly, to the magnetic meridian, the earth acting like a magnet whose N. pole would be on the S., and whose S. pole would be on the N. of the earth. Under the influence of the Magnetism of the globe, therefore, the moveable conductor moves in a direction the reverse of that to which it would tend when influenced by a magnet alone; the two motions tend to counteract each other, and this complication Ampère obviated by making the system *astatic*, that is, by so arranging it that there shall be equal and similar horizontal currents running in contrary directions, and equal and similar vertical currents running in the

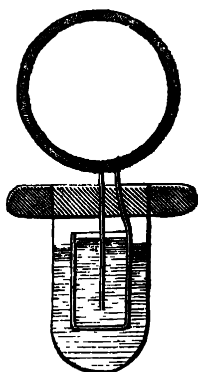
same direction, as shown in Fig. 314, where the two rectangles are represented as situated each on a different side of the axis of rotation, but on the same plane; the current traversing the two associated rectangles in different directions, as shown by the arrows. The action of the earth's Magnetism on this system is null, because it gives to one of the rectangles a tendency to move in a direction the reverse of the other.

Fig. 314.



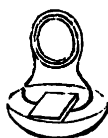
(939) In order to give the moveable conductor perfect freedom of motion, which in Ampère's arrangement it could not have, because of the horizontal arms of the vertical supports, M. De la Rive contrived the ingenious little apparatus shown in Fig (315). It consists of a cylindrical glass vessel, having a cork float attached to its upper end. Into this vessel is inserted a small voltaic combination, formed on Dr. Wollaston's plan, and consisting of a plate of zinc surrounded by a copper plate, the zinc plate being insulated upon its edges. A copper wire affixed by soldering to both these plates, is made into the form of a ring, consisting of several coils of the wire, which is besides insulated, by being wrapped round with silk thread: upon pouring diluted acid into the glass vessel, and placing the plates in it, voltaic action commences, and is manifested by placing the apparatus afloat in water, when the coil will have a tendency to take a position in the plane of the magnetic meridian, and will exhibit all the effects of the attractive and repulsive tendencies which have been described above, when a strong bar magnet is brought near it on either side. If the magnet be sufficiently slender to pass through the ring, the following curious phenomenon will be observed: If the pole be presented to it on the side where attraction takes place, the ring will move towards it till it arrives at the pole, and then proceed onwards in the same course, the magnet being held in the axis of the ring, till it reaches the middle of the magnet, but there it seems inclined to stop; and then, after a few oscillations, it settles as in a position of equilibrium; for, if purposely displaced, by bringing it forwards towards the other pole, it returns with a force which shows that it is repelled from that other pole. Let the magnet now be withdrawn, and turning it half round,

Fig. 315.



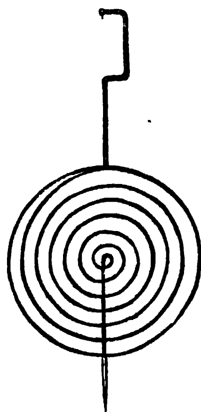
so that its poles are in directions the reverse of what they were at first, and holding the ring in one hand, let the magnet be again introduced into it with the other hand, until it is half way through. Under these circumstances, it is just possible that it may have been brought into such a situation as that the ring may again be in equilibrium, undetermined in what direction to move; but the slightest change in this position, causes it to move with an accelerated velocity towards that pole which is nearest to it; and getting entirely clear of the magnet, it is projected to a considerable distance from it. At length, however, it stops, and, gradually turning round, presents the opposite face to the magnet; attraction now takes place, and the ring returns to the magnet with a force equal to that with which it had before fled from it; and passing again over its pole, finally rests in its position of equilibrium, encircling the middle, or what may be termed the equator, of the magnet. In the former position it was equally attracted by the two poles of the magnet, in the latter it is equally repelled; and accordingly, the first was an unstable and the last a stable equilibrium. There are few experiments better calculated to exhibit to a class in a lecture-room the mutual affections of a magnet and an electrified wire than this: the motions of the floating coil are less impeded by setting it afloat in a small thin varnished wooden dish as shown in Fig. 316, where the voltaic pair is represented as being placed in a horizontal position in a little bowl; the whole is then set afloat in a large basin or trough of water, and on pouring a little dilute sulphuric acid into the bowl, the coil will be found to be surprisingly sensible to the influence of a magnet, and will be attracted and repelled at the distance of several inches.

Fig. 316.



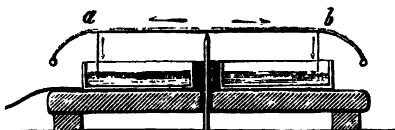
(940) The directive tendency of an electrified wire may also be strikingly exhibited by bending it into the form of a spiral, and either connecting it with the floating galvanic arrangement, or suspending it delicately by a hook as in Fig. 317, and passing the voltaic current through it; the plane of the spiral will be found to place itself E. and W., the positive current ascending on the W. side, and descending on the E., taking the same course as the hands of a watch when it is held on edge with the plane of the dial lying E. and W. facing S. That side of the spiral which is towards the N. acts as the N. pole, and the S. side has an opposite polarity. Each side powerfully attracts iron filings.

Fig. 317.



(941) The rotation of horizontal currents by the influence of the Magnetism of the earth is demonstrated by the apparatus shown in Fig. 318. It consists of a copper dish filled with dilute sulphuric acid, in the centre of which the horizontal wire, *a b*, terminated with two balls, is balanced on a fine point; from near the ends of this wire two short wires drop vertically into the acid; on causing the voltaic current to pass in a contrary direction through the two halves of the wire, as indicated by the arrow heads in the figure, a continuous rotatory movement is established. The rotation is from E. to W. when the current passes from the centre to the circumference, and from W. to E. when it moves from the circumference to the centre of the wire. If the N. pole of a magnet be held underneath the apparatus, a great increase in the velocity of the rotation takes place; but if the same pole be presented above, the velocity is diminished, the magnet in the first instance co-operating with, and in the second instance contending against, the action induced by the earth; the reverse effects are produced by the S. pole. If the magnetic pole be held in the same horizontal plane as the wire *a b*, its action is altogether null.

Fig. 318.

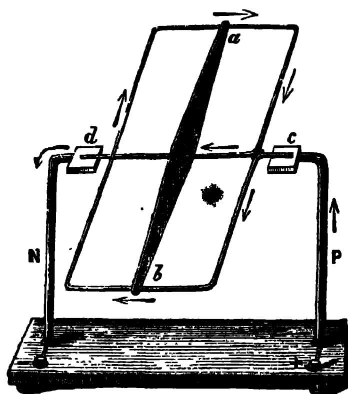


(942) The following curious phenomena were observed by Sir H. Davy. He plunged the two poles of a powerful battery vertically at about an equal distance from the centre and circumference into mercury contained in a shallow dish and covered with acidulated water; no particular appearance was observed till one of the poles of a powerful magnet was brought near, when the mercury became agitated, and began to revolve with rapid rotation round each wire, the direction of the motion being determined by that of the current; and by the position and nature of the magnetic pole. The rotation was most rapid when the two opposite magnetic poles were brought into action, one being held above and the other below the mercury. Two thick copper wires covered with wax, but with their ends clean, were passed through the bottom of a glass dish about 3 inches apart, and projecting about 1 inch from the bottom of the dish, which was then filled with mercury to the depth of about a line above the tops of the wires. On passing a powerful current through the wires, the mercury became violently agitated, its surface above each wire rose in the form of small cones, which fell in little waves in all directions, the only quiescent spot being where the waves met at the centre of the mercury between the two wires. On approaching gradually one of the poles of a powerful magnet to the summit of one of the cones,

it gradually fell, and, as the magnet advanced, a funnel-shaped cavity was formed in the mercury, the apex of which descended nearly to the top of the wire. Fused tin exhibited the same phenomena.

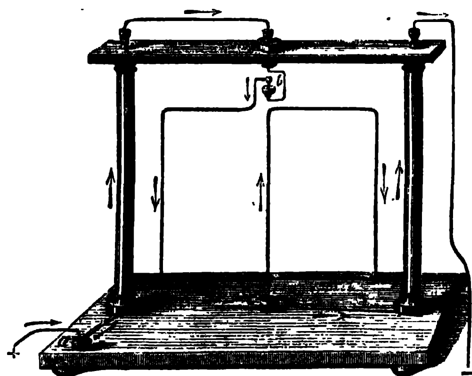
(943) By the apparatus shown in Fig. (319) Ampère demonstrated that a rectangular wire, if arranged so as to be moveable round a horizontal axis, and in perfect equilibrium, in all its positions round this axis, will, if placed with its axis of motion at right angles to the magnetic meridian, place itself steadily in the plane of the magnetic equator, that is, in a plane perpendicular to the line of the dip, when traversed by a voltaic current. The rectangular frame of copper wire is fixed at right angles to a tube of wood, which serves as an axis, and in the same plane, a lozenge-shaped bar of wood, *a b*, is placed. The current ascending the pillar, P, enters the rectangle through a steel pivot, resting on the metallic plate *c.*; it traverses the wire in the direction of the arrows, and finally descends through the plate *d*, down the metallic pillar, N. The moment the electric current is established through the wire, it begins to oscillate, and finally takes up a position in the plane of the magnetic equator. On reversing the direction of the current, the magnetic polarity of the wire becomes reversed, and the rectangle turns round, so as still to place itself in the same plane as before, but with its faces turned in the opposite directions.

Fig. 319.



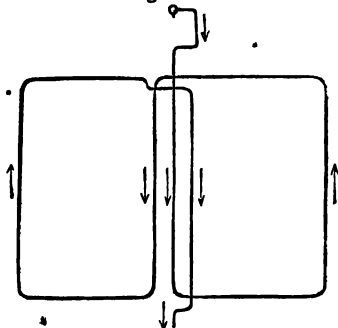
(944) *Mutual Action of two Parallel Electrical Currents.* — When two metallic wires are traversed simultaneously by an electrical current, the wires are either attracted towards, or repelled from each other, according to the relative directions of the two currents; when they move in the same direction through the wires, there is a mutual attraction; when they move in a contrary

Fig. 320.



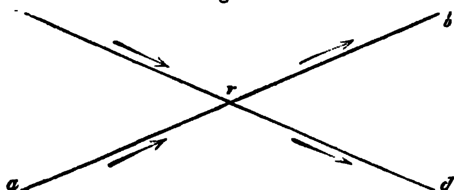
direction there is a mutual repulsion set up between the conductors. These phenomena, as well as the development of the mathematical laws which govern them, were discovered by Ampère, and may be illustrated by means of the apparatus shown in Figs. 320 and 321. Two copper columns are fixed vertically on a wooden base. The positive electrode of a battery of 5 or 6 pairs is made to communicate with the left hand pillar through the mercury cup *a*; the voltaic current ascends this pillar, and enters the moveable rectangular copper wire through the mercury cup *b*, leaves it through the cup *c*, and ascending the right hand column completes the circuit through a wire communicating with the negative electrode. By observing the direction of the arrow heads, it will be perceived that the voltaic current is moving in different directions through the fixed pillars, and through those portions of the moveable conductor adjacent to them; the rectangle is, therefore, repelled in accordance with Ampère's law; but by arranging the wire as shown in Fig. 321. the current is caused to move in the same direction through the pillars and the adjacent parts of the moveable conductor, and attraction consequently results. The intensity of these attractions and repulsions is in proportion to the length of the vertical sides of the rectangles, and to the square of the intensity of the current in circulation, it would be also in the inverse ratio of the simple distance, if the fixed columns could be considered as having a length infinite in relation to that of the moveable conductors.

Fig. 321.



(945) *Laws of Angular Currents.*—Two rectilinear currents which diverge from, or converge to a common point, mutually attract. If one converges and the other diverges, mutual repulsion ensues. Thus let *ab* and *cd* (Fig. 322) be two currents crossing at the point *r*, there will be attraction between the two parts *a r*, *c r*, because the currents are both converging towards *r*, and also between *b r*, *d r*, because they both are diverging from that point; but there will be repulsion between *a r* and *r d*, and also between *c r* and *r b*, because, while *a r* and *c r* are

Fig. 322.

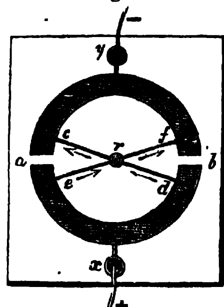


approaching the point *r*, *r b* and *r d* are receding from it. These laws may be demonstrated by the apparatus shown in Figs. 323 and 324. Two semicircular grooves, separated by the non-conducting divisions *a* and *b*, are cut in a block of wood; a very mobile copper needle, *c d*, is poised in the centre on a pivot; the ends of this needle, which are of iron, are bent at right angles and dip into mercury contained in the grooves; a little below this first needle is placed a second, moving independent of the other, like the hands of a watch, its points being also at right angles and dipping into the mercury channels. The electrical current enters through *x*, and passing over the two needles escapes at *y*.

Fig. 323.



Fig 324.

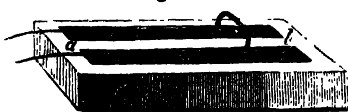


The needles being in the position *c d*, *e f*, repulsion takes place, but attraction ensues when they are placed in any other position whatever, such that the angle *c r f*, shall be less than a right angle. From this it follows that an angular current *a b c*, tends to become straight; the parts *a b* and *b c* exercising a mutual repulsion. This repulsion not only tends to bend back *b c* into a prolongation of *a b*, but it is still exercised when this condition is fulfilled; in other words, *the contiguous portions of the same rectilinear currents repel each other*. By means of the apparatus (Fig. 326) this consequence so important to his theory was demonstrated by Ampère. A hollow cut out of a block of wood, is divided into two compartments by the non-conducting division *a b*; a silk covered copper wire is so bent that in each compartment it shall present a horizontal branch parallel to the division; these branches or arms are covered with wax, except at their extreme ends, where they are bent so as to touch the mercury. On passing a strong current through the wire it immediately recedes, showing an apparent repulsion between the current passing through the mercury, and that traversing the wire. Pouillet ("Elements de Physique" tome i, p. 562), does not think that this experiment demonstrates the fact in a manner completely satisfactory, because we have not sufficient knowledge of the mode in which a voltaic current passes from a liquid to

Fig. 325.



Fig. 326.



a solid; if for instance, one portion of the current should pass obliquely to the wire, the phenomenon of repulsion would be equally exhibited.

(946) *Rotation of a Current by the Action of a Current.*—If we imagine a fixed indefinite current moving in the direction, *a b*, Fig. 327, and another current, *c d*, moving in a direction parallel to itself, the point of crossing being at *r*, there will be attraction about the angle *b r d*, between the parts *r b* and *c d*, because in both the current is moving from the summit of the angle, or from the point of crossing; there will, on the contrary, be repulsion about the angle *a r d*, because on one side, *a r*, the current is approaching to, while on the other side, *c d*, it is receding from the point of intersection. These two forces give rise to a resultant parallel, *a b*, which tends to urge incessantly the current *c d* from *a* towards *b*. If the fixed current, *a b*, is formed into a circle, it is evident that *c d* should revolve indefinitely; and that it actually does so may be proved by the little apparatus shown in Fig. 328. It consists of a glass vessel, containing acidulated water, round which is wound a silk-covered copper wire, through which a voltaic current is caused to circulate. In the centre of this vessel there is fixed a copper pillar, B, surmounted by a small capsule for containing mercury; in this is plunged an iron point supporting a copper wire, D C, bent at a right angle at either end, and carrying the copper ring, *m*, which dips into the acidulated water. The voltaic current entering at A, after having made several circuits round the glass vessel, passes up the pillar B, from the cup of which it proceeds in both directions along the copper wire and reaching the copper ring is transferred to the acidulated water, into which is plunged the negative electrode, E, of the pile; the moment the circuit is complete, the whole moveable system begins to revolve in a direction contrary to that of the fixed current.

Fig. 327.

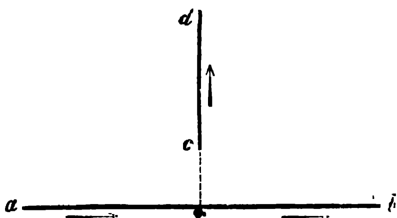
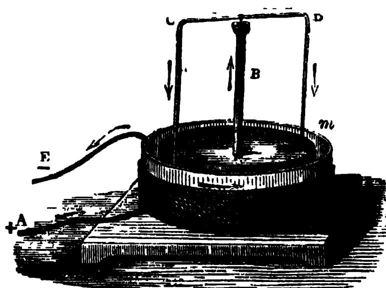
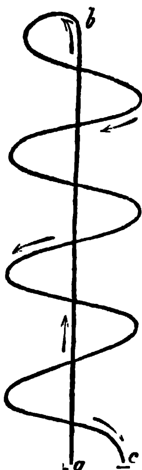


Fig. 328.



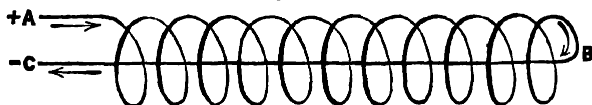
(947) *Sinuous Currents; Solenoids.*—If a current, instead of

Fig. 329.



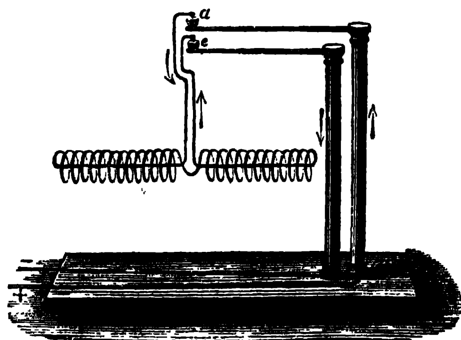
following a rectilinear course, deviate alternately to the right and to the left, its action is the same with that of a rectilinear current of the same extension. This may be proved by passing a current through a wire, *a b c*, partly rectilinear and partly sinuous or zig-zag, and bringing it near to a mobile conductor (Fig. 329); the latter will be neither attracted nor repelled, proving that the sinuous portion, *c b*, is in exact equilibrium with the rectilinear portion, *a b*. The combination of a rectilinear with a sinuous current is called a *solenoid*. It is a system of circular currents, equal and parallel, formed by twisting a silk-covered copper wire, corkscrew-fashion, back upon itself; but to make it perfect, the straight part of the wire must be as exactly as possible in the centre of the helix. Thus arranged, when the circuit is traversed by a current, the action of the solenoid in the direction of

Fig. 330.



its length, A B, is destroyed by that of the rectilinear current B C, and the only effect produced is due to the system of circular currents, equal and parallel, moving in a direction perpendicular to its axis. Now, as the action of fixed currents on moveable ones is to bring them into a position parallel to themselves, with their currents moving in the same direction, a solenoid freely suspended on a vertical axis should, when acted on by a rectilinear current, range itself with its circles parallel to that current. It is accordingly found that

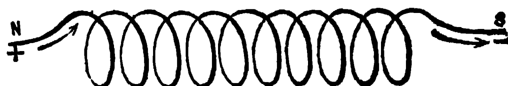
Fig. 331.



on passing a strong voltaic current through a solenoid suspended from two mercury cups, as shown in Fig. 331, so as to allow it perfect freedom of motion round a vertical axis, and passing at the same time underneath, and parallel to its axis, a rectilinear current, the solenoid turns itself across that current taking up a position with its circles

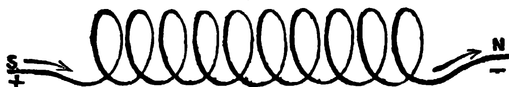
parallel to it. If instead of passing the rectilinear current *horizontally* underneath the solenoid, it be passed *vertically* and near one end, the latter is either attracted or repelled according as the currents are passing in the same or in opposite directions, through the wire and through the contiguous parts of the solenoid. Two solenoids exhibit towards each other the phenomena of attraction and repulsion in a manner precisely similar to two magnets, and a solenoid is influenced by a magnetic bar precisely as another magnet would be. In short, a solenoid has all the properties of a magnet, and when suspended, as shown in Fig. 331, and traversed by a strong electric current, it will range itself with its axis parallel to the direction of the declination needle. If the solenoid be a *right*

Fig. 332.



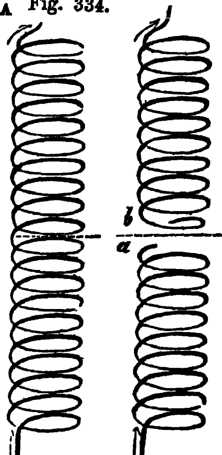
handed helix, its wire being turned from left to right, then the extremity at which the current enters has the magnetic properties of a N. pole, and the extremity at which it leaves the helix those of a S. pole. If the helix be left-handed, its wire turning from right

Fig. 333.



to left, then the extremity at which the current enters has the properties of a S. pole, and that at which it leaves the helix has those of a N. pole. When a magnetic bar is broken across, each fragment is itself a perfect magnet, the two fractured ends having an opposite polarity; it is precisely the same with a solenoid: suppose, for example, A B to represent a solenoid extending indefinitely on either side of the point *m*, and traversed by a current in the direction of the arrows, the extremity A is a S. pole, because on looking at the face of this terminal circle the ascending current is observed to be moving from left to right; suppose now the solenoid to be cut in two at *m*, the *a* end will be a S. pole, and the end *b* a N. pole, because on looking at the face of the terminal circle of the latter, the ascending current is seen to be moving from right to left. It is evident, therefore, that there will be attrac-

Fig. 334.



tion between *a* and *b*, and it may be proved moreover that this attraction is, as in the case of magnets, inversely as the square of the distance between *a* and *b*.

(948) A beautiful exemplification of the mutual attraction of conducting wires carrying voltaic currents moving in the same direction, is afforded by Roget's spiral (Fig. 335). It consists of a loose coil of copper wire, the upper end being either held by a binding screw or suspended by a fibre of silk, and the lower end (which should be amalgamated) just touching the surface of some mercury in a little cup, communicating with the negative electrode of a pretty strong voltaic battery. On making a contact between the upper extremity of the spiral and the positive electrode, the coils being all traversed by a current in the same direction, will mutually attract each other; the entire spiral being hereby shortened, the lower end leaves the mercury, and the contact with the battery is broken; the weight of the wire thus causes it again to fall into the mercury, and the passage of the current is restored; in this way a rapid series of longitudinal vibrations is produced, accompanied by a snapping noise, and a succession of bright sparks. Again, suspend from a horizontal rod two similar compound spirals, each consisting of several layers of insulated copper wire superposed, and send a strong current through each in the same direction; they will attract each other powerfully, even at a distance of several inches; now reverse the direction of the current in one of the spirals, upon which a repulsion equally powerful will be set up between them. It must be borne in mind that in flat spirals as well as in helices, the nature of the magnetic poles is determined by the direction of the *spirals* as well as by the direction of the *current*. In the right-hand spiral (Fig. 336.) the end at which the current enters has the magnetic properties of a N. pole and in the left-hand helix (Fig. 337), the end at which the current enters has the properties of a S. pole.

Fig. 335.

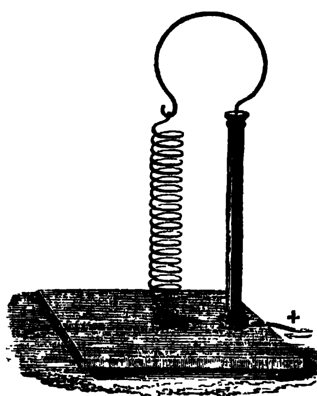


Fig. 336.

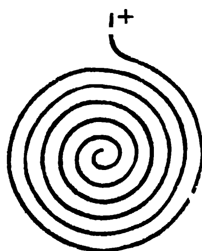
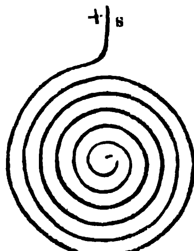
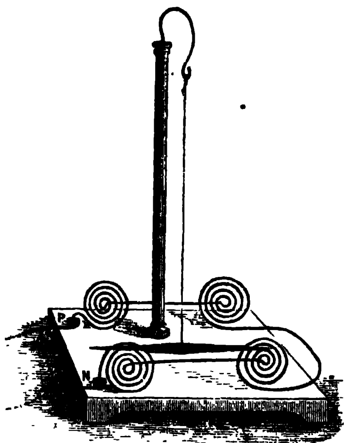


Fig. 337.



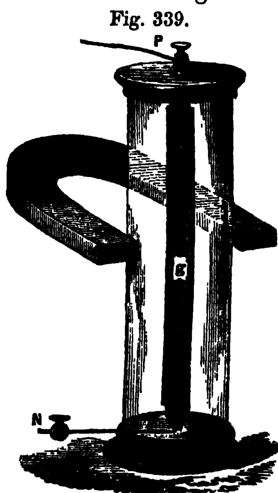
(949) *Galvanometers.*—We have already described the construction of the various forms of this valuable instrument (426 *et seq.*), and the preceding considerations render it probably unnecessary to add anything with reference to the principles on which their action depends. In Fig. 338, is shown the vertical spiral coil, galvanometer described by Dr. Roget (*Library of Useful Knowledge*, Electro-magnetism, No. 44). The needle is suspended from its centre by a fine thread between four vertical spiral coils, the centres of which are brought very near to the poles of the needle. The same current is made to circulate through all the four spirals, the turns of which are directed so as to produce repulsion of the contiguous pole on the one side, and attraction of the same pole on the other side. In each disc the force acting perpendicularly to the plane of the discs is multiplied in proportion to the number of the circumvolutions of the wire, and the spiral turns being made in the same directions in all the discs, their actions will concur in producing in the needle a deviation in the same direction, and the total force will be four times that of a single disc.

Fig. 338.



(950) The action of a magnet on a moveable conductor has also been made available as an extremely delicate test of a weak galvanic current. (*Cumming's Electro Dynamics.*) A slip of gold leaf *g* (Fig. 339) is retained loosely between two forceps, each terminating in a mercury cup or binding screw, for establishing the communications by which the current is transmitted through the leaf. The whole is enclosed in a cylindrical glass case, the middle of which is placed between the poles of a powerful horse-shoe magnet, so that the gold leaf may be nearly equidistant from them when the circuit is complete. The latter is attracted or repelled laterally by the poles of the magnet according as the current is ascending or descending; the broad surface of the leaf becoming convex towards

Fig. 339.



the magnet in the one case, and concave in the other. This principle has been adopted by Highton in one of his patented electric telegraphs.

(951) Mr. Faraday, whilst making experiments to ascertain the position of the magnetic needle relative to the connecting wire, was led (*Quart. Jour. of Science*, xii., p. 74) to some new views of electro-magnetic action. On placing the wire perpendicularly, and bringing the needle towards it to ascertain the attractive and repulsive positions with regard to the wire, he found them to be *eight*—2 attractive and 2 repulsive for each pole. Thus, allowing the needle to take its natural position across the wire, and then drawing the support away from the wire slowly so as to bring the N. pole, for instance, nearer to it, there was attraction, as was to be expected; but on continuing to make the end of the needle come nearer to the wire, repulsion took place, though the wire still was on the same side of the needle. If the wire was on the other side of the same pole of the needle, it repelled it when opposite to most parts between the centre of motion and the end; but there was a small portion at the end where it attracted it.

Fig. 340.

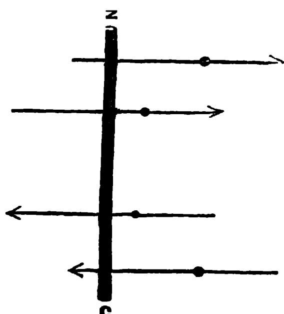


Fig. 341.

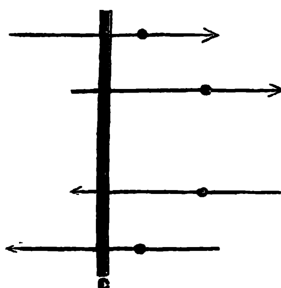


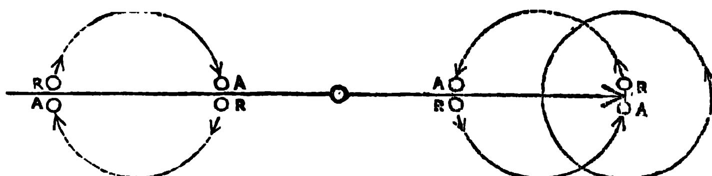
Fig. 340 shows the positions of attraction for the N. and S. poles. Fig. 341 the positions of repulsion.

(952) On making the wire approach perpendicularly towards one pole of the needle, the pole passed off on one side in that direction which the attraction and repulsion at the extreme point of the pole gave; but if the wire were continually made to approach the centre of motion by either the one or the other side of the needle, the tendency to move in the former direction diminished; it thus became null, and the needle was quite indifferent to the wire, ultimately the motion was reversed, and the needle powerfully endeavoured to pass the opposite way. From this it was evident that the centre of

the active portion of either limb of the needle, or the true pole as it may be called, *is not at the extremity* of the needle, but may be represented by a point generally in the axis of the needle at some little distance from the end. It was evident also that this point had a tendency to revolve round the wire, and necessarily, therefore, the wire round the point; and as the same effects in the opposite direction took place with the other pole, it was evident that each pole had the power of acting on the wire by itself, and not as any part of the needle, or as connected with the opposite pole.

In Fig. 342, sections of the wire in its different positions to the needle are represented—the active poles by two dots; and the arrow heads show the tendency of the wire in its positions to go round these poles.

Fig. 342.



From these facts it follows that both attraction and repulsion of conducting wires are compound actions; that there is no attraction between the wire and either pole of the magnet, and that the wire ought to revolve round the magnetic pole, and the magnetic pole round the wire. By the following ingenious apparatus Faraday proved this to be really the case.

Into the centre of the bottom of a cup, as in the vertical section, Fig. 343, a copper wire *c* D, was inserted; a cylindrical magnet *n s*, was attached by a thread to the copper wire, *c*, and the cup was nearly filled with mercury, so that only the N. pole of the magnet projected. A conductor, *a b*, was then fixed in the mercury, perpendicularly over *c*. On connecting the conducting wires with the opposite ends of the battery, a current was transmitted from one wire through the mercury to the other. If the positive current descended, the N. pole of this magnet immediately began to rotate round the wire *a b*, passing from E. through the S. to W., *i. e.*, in the direction of the hands of a watch; but if the current ascended, the line of rotation was reversed. Conversely, a magnet was fixed in a vessel of mercury, and the conducting wire hung from a hook above it, the end just dipping into

Fig. 343.

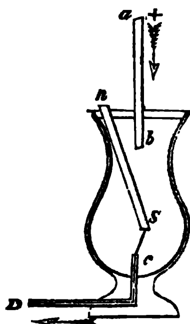
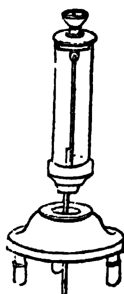


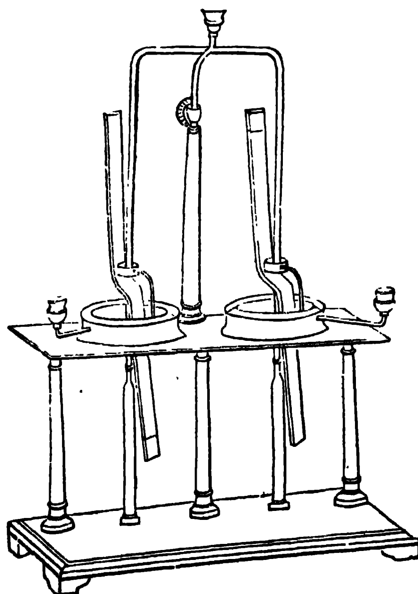
Fig. 344.



the fluid; the electric current being then transmitted through the moveable conductor, Faraday found that the free extremity instantly began to revolve round the pole of the magnet, in a direction similar to the last. A good contrivance for exhibiting this, is shown in Fig. 344.

(953) In order to obviate the necessity of employing so much quicksilver, which, by the resistance which it offers to the revolution of the magnet, greatly diminishes the velocity of the rotation, the apparatus in Fig. 345, was devised by Mr. Watkins. It exhibits the contrary poles of two magnets rotating about two electrified wires. Two flat bar magnets, doubly bent in the middle, and having agate cups fixed at the under part of the bend, by which they are supported upon upright pointed wires, are affixed in the basis of the apparatus, upon which they turn round as upon an axis. Above the agate cups, on the upper part of the bend, small cisterns to hold mercury are also formed. Two circular troughs to contain mercury, are supported

Fig. 345.

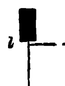


upon a stage, affixed to the basis, having holes in their centres, to allow the magnets to pass through them. A bent pointed wire is affixed into the cisterns of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage; and through the sides of the trough, wires are passed, entering into the mercury contained in the troughs, and bearing at their ends other cups to hold mercury. To steady the motion of the magnets, wire loops are affixed to them, which embrace the upright pointed wires on which the magnets rest. A hollow pillar is firmly affixed to the stage, in which a bent wire supporting another cross wire is inserted, and is capable of being raised or lowered, and secured

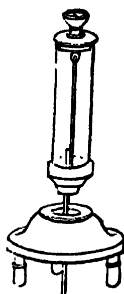
at any required height by a binding screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small cisterns affixed upon the magnets. A third cup to contain mercury is also provided at the top of the cross wire, and a communication being made with the battery by means of uniting wires dipping into the mercury in the cups, the wire from the positive end of the battery being placed in the upper cup, and the wire from the negative end in each of the lower cups, the magnets will begin to rotate in opposite directions, and those directions may be reversed, by changing the situations of the uniting wires. Two batteries should here be employed, in order to make both the magnets revolve with the desired velocity; and attention must be paid, when using two batteries, that the currents of Electricity flow in the same direction; otherwise, the phenomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction. (*Popular Sketch of Eletro-magnetism*, by Francis Watkins.)

(954) Thus it will be seen that the direction of the rotation imparted by a fixed current to a moveable pole, will be the same as that which the same pole imparts to the same current. Suppose *w* (Fig. 346) to represent a section of a conducting wire, along which a positive current is descending, and *n* the N. pole of a magnet; the influence of *w* on *n* will be to impel it in the direction of the arrow; but *n* will also react on *w*, and tend to produce in it motion in an opposite direction, as exhibited by the arrow attached to *w*. Each is supposed to describe a circle round the other, moving in the same direction as the hands of a watch; and if *w* and *n* were at liberty equally to move, they would have a tendency to rotate round the line between them.

Fig. 346.



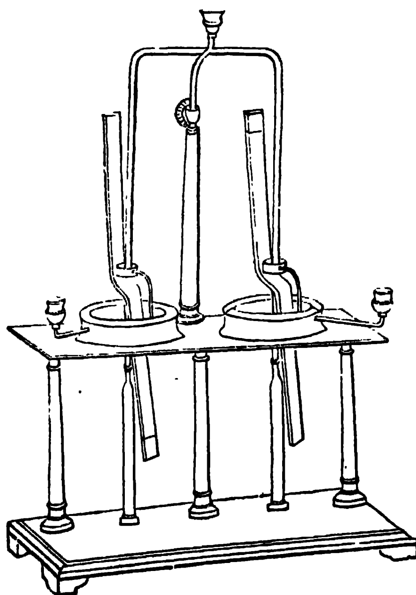
(955) Ampère first succeeded in effecting the rotation of a magnet round its own axis. In his original experiment the magnet was allowed to float, without a support, in a vessel of mercury, being kept in a vertical position by a weight of platinum attached to its lower end. The object was to make the electrical current pass through one half of the magnet itself, and then to divert it from its course, and make it pass away in such a direction as that it should not affect the other half. The reason of this is evident: suppose a positive current be made to descend a magnet placed vertically, its N. pole being uppermost, it would tend to urge that pole round from left to


Fig. 344.

the fluid; the electric current being then transmitted through the moveable conductor, Faraday found that the free extremity instantly began to revolve round the pole of the magnet, in a direction similar to the last. A good contrivance for exhibiting this, is shown in Fig. 344.

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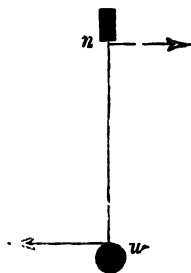
Fig. 345.



at any required height by a binding screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small cisterns affixed upon the magnets. A third cup to contain mercury is also provided at the top of the cross wire, and a communication being made with the battery by means of uniting wires dipping into the mercury in the cups, the wire from the positive end of the battery being placed in the upper cup, and the wire from the negative end in each of the lower cups, the magnets will begin to rotate in opposite directions, and those directions may be reversed, by changing the situations of the uniting wires. Two batteries should here be employed, in order to make both the magnets revolve with the desired velocity; and attention must be paid, when using two batteries, that the currents of Electricity flow in the same direction; otherwise, the phenomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction. (*Popular Sketch of Eletro-magnetism*, by Francis Watkins.)

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Fig. 346.



(955) Ampère first succeeded in effecting the rotation of a magnet round its own axis. In his original experiment the magnet was allowed to float, without a support, in a vessel of mercury, being kept in a vertical position by a weight of platinum attached to its lower end. The object was to make the electrical current pass through one half of the magnet itself, and then to divert it from its course, and make it pass away in such a direction as that it should not affect the other half. The reason of this is evident: suppose a positive current be made to descend a magnet placed vertically, its N. pole being uppermost, it would tend to urge that pole round from left to

right, but its influence on the S. pole would be just the reverse, tending to urge it from right to left; or if two electrical currents be supposed, corresponding to the vitreous and resinous electricities, the tendencies would be the same; and here it may be as well to mention, that in describing the phenomena of Electro-magnetism, we shall, to avoid tediousness, adopt the language of a single fluid, and suppose, that in the connecting wire of a voltaic battery, the electrical current is passing in one stream from the positive to the negative end.

(956) In Ampère's experiment, the electric current, after traversing the upper half of the magnet, passes into the mercury, and being diffused through it, acts in no sensible degree on the lower half, and does not interfere with the rotation produced by its influence on the upper pole.

It is, however, better to carry off the current by a different channel, and this is effected by adopting the form of apparatus, shown in

Fig. 347.

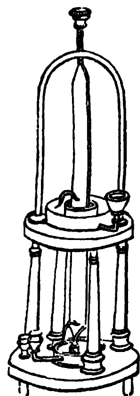
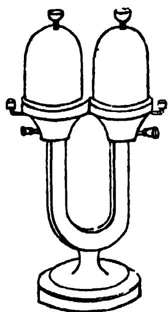


Fig. 347. It is thus constructed by Mr. Watkins. A flat bar magnet is supported in a vertical position by an upright metal wire, affixed in the basis of the apparatus, and having a hole in its centre, containing an agate cup, to receive the lower pointed end of the magnet; its upper end turns in another hole, made in a vertical screw, with a milled head to turn it by, which is passed through a screw hole, made in an arched piece of wire, affixed to the upper part of the basis. Around the first mentioned vertical wire a cistern to contain mercury is provided; and another, having a hole in its centre, to allow the magnet to pass through, and revolve within it, near the middle of the magnet. These cisterns have metal wires projecting into them, through their sides, to support cups which contain mercury, to effect the communication with the voltaic battery by means of uniting wires. Into the magnet two small bent and pointed wires are affixed, the ends of which dip into the mercury contained in the cisterns. When the voltaic circuit is complete, the magnet begins to rotate within the Electricity, which it conducts itself, as it in fact forms part of the circuit; the rapidity of the revolutions of the magnet depending upon the delicacy of the sustaining point, the strength of the magnet, and the power of the battery employed. If it be desired to actuate a large magnet, it is necessary that an addition to the apparatus should be made, by providing a cup, affixed to the vertical screw, to contain mercury, by which contrivance, and by employing an additional battery, a current of Electricity can be

passed from the top of the magnet to its equator; and, as in the first mentioned case, an opposite current can be passed from its lower end to the equator, an additional force is obtained. The current from the second battery must, of course, be sent along the upper half of the magnet, in a direction contrary to that which passes through the lower pole; but since the rotatory force is proportional to the power of the voltaic battery employed, it is probable that the second battery would be equally efficacious, if it were employed in increasing the strength of the first by being joined to it. The ends of the wires should be amalgamated, by rubbing them first with nitrate of mercury and then dipping them into the clean metal.

(957) Fig. 348 represents an apparatus to exhibit the rotation of a conducting body round its own axis, and is exactly the converse of the last experiment. In the former case, the electric current was applied in the interior of the magnet, but here means have been devised for procuring the action of the magnet, from the interior of the conducting body. In the place of the wire, therefore, a hollow metallic cylinder is employed, in the axis of which the influencing magnet can be placed. Mr. Barlow devised this instrument, and the figure shows the arrangement on a horse-shoe magnet by Mr. Watkins. A horse-shoe magnet is supported vertically upon a stand, having holes formed in the centres of its ends. Two wooden circular troughs are secured by binding screws upon the arms of the magnet, to contain mercury. Into the holes in the centres of the ends of the magnet, two conical pointed wires are inserted, which are affixed in the middle of two hemispherical cups, united to cylinders, the rims of which are formed into points, which are dipped into the mercury contained in the circular troughs. Upon the top of each hemisphere is placed a small platinum cup to contain mercury. Other cups for holding mercury are supported on the external ends of bent wires, which pass through the sides of the circular troughs into the mercury contained therein. When a stream of voltaic Electricity is passed through this apparatus by means of connecting wires, placed in the mercury contained in the upper and lower cup, the cylinders commence revolving in opposite directions, that cylinder on the N. pole, and down which the current is descending, moving from left to right; but if the two upper cups be united by a wire, and the lower cups connected with the positive and negative extremities of the voltaic battery, the same stream will traverse both sides of the apparatus, passing upwards in one cylinder, and downwards in the other; and the rotations

Fig. 348.



will now, from the contrary influences of the two poles, be in the same direction in both cylinders.

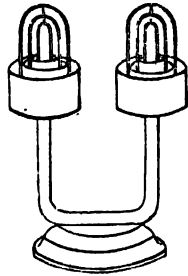
(958) Faraday has shown, that the results in this last experiment, are the same when the magnet and conductor are united together; for on fixing a thin piece of wood on the upper end of a magnet, loaded at its lower extremity with a platinum weight, floating in a vessel of quicksilver, and attaching to the wood an arch of strong wire, the whole apparatus commenced revolving on the transmission of the electric current through it; on the other hand, when a hollow cylinder of metal was balanced on a vertical axis of wood, and acted on by the poles of a magnet placed *outside*, the rotatory force was very feeble. This affords us means of explaining the circumstances of the rotation of a magnet about its own axis, for the explanation of that experiment will very much depend on the course which the current of Electricity is supposed to take in its passage through the magnet. If it be supposed to pass through the interior, along the axis of the magnet, it would then occasion rotation by its influence on the parts of the magnet that are situated nearer the surface; but if the course of the current be supposed to be along the surface, it will itself be influenced by the polarity of those portions of the magnet which lie near the axis, and the rotatory tendency impressed upon it will produce the rotation of the magnet, which will, of course, be carried along with it. This, it will be seen, corresponds with the rotation of a conducting body round its own axis, a magnet being in the centre; and it has been shown above, that the circumstance of the magnet and conductor being immoveably joined makes no difference in the results.

(959) Another fact is made apparent by this last experiment, which is, that the electro-magnetic influence of the conductor takes place equally when the electrical current is diffused over a considerable surface, as when it is concentrated in a single wire; in the cylinder, every filament of which it is composed may be supposed to conduct its share of the current, and thus contribute towards the general effect.

(960) A magnetic needle is found to be influenced by the current of Electricity that is passing through the voltaic battery from its *positive* to its *negative* pole, as well as by the wire that completes the circuit, or in other words, every part of the circuit exhibits the same electro-magnetic properties; and as action always implies an equal and corresponding re-action, the magnet may be supposed to have a tendency to move the battery, equal to that which the battery has to move it. This tendency was first actually exhibited by a very ingenious contrivance of Ampère, and which Mr. Watkins

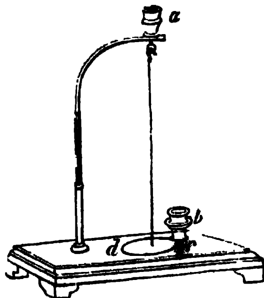
has applied to each of the poles of a horse-shoe magnet, as shown in Fig. 349. It consists of a horse-shoe magnet, firmly fixed to a stand at its bent part; its two ends being made round, and having a small hole in the centre of each, at the bottom of which hole, an agate cup is placed, in which pointed wires fixed to the parts presently to be described are made to revolve. A double cylindrical copper vessel, having a bent metal wire fixed to the top of its innermost cylinder, with a vertical wire pointed at both ends fixed in the middle of that bent wire, is hung upon the upper end of each pole of the magnet, the lower points of the vertical wires of each vessel entering the holes, formed as above described, in the magnet for that purpose. Two hollow cylinders of zinc, each furnished with similar bent wires, having holes made in the under sides of each, are then placed within the double copper vessels; the holes in the bent wires being hung upon the uppermost pointed ends of the vertical wires before mentioned. Diluted acid being then poured into the space between the copper cylinders, the voltaic action commences, and presents the phenomena of the whole four cylinders revolving upon their axes, the copper vessels revolving in opposite and contrary directions, and the zinc cylinders turning in opposite directions to them: the rapidity of their revolutions depending upon the strength of the acid and the delicacy of their suspension *

Fig. 349.



(961) Numerous amusing experiments have been devised for exhibiting the vibratory tendencies of electrified wires when under the influence of magnets. Fig. 350 represents an arrangement by Mr. Marsh. It consists of a slender wire, suspended from a loop and capable of free motion; its lower end is amalgamated, and dips into a small cistern of mercury; the cups *a* and *b* are filled also with mercury, and through them the electrical current is passed down the loose wire; no motion of this wire is perceptible until a horse-shoe magnet is placed in a horizontal position on the basis, with its poles enclosing the wire, when it is instantly urged either forwards towards *c*, or backwards towards *d*,

Fig. 350.

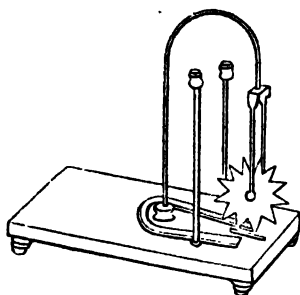


* The zinc cylinders revolve with great rapidity, but from the superior weight of the copper cylinders when filled with the exciting liquor, it is rarely that a rapid rotation can be exhibited in them.

according to the position of the poles, and the direction of the current. In either case it is thrown out of the mercury, and the circuit being thus broken, the effect ceases, until the wire falls back again by its own weight into the mercury; when the current being re-established, the same influence is again exerted, the phenomenon is repeated, and the wire exhibits a quick succession of vibratory motions.

(962) This vibratory motion is easily converted into one of rotation by employing a spur wheel, as in Fig. 351. The radii of the wheel must be so arranged that each ray shall touch the surface of the mercury before the preceding ray shall have quitted it. The direction of the motion depends of course on the same circumstances as were before mentioned.

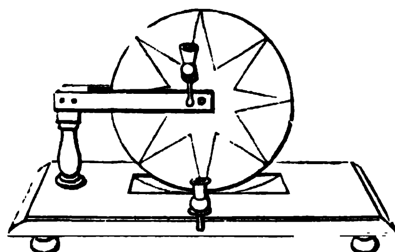
Fig. 351.



This forms a very brilliant experiment when a powerful battery and a strong magnet are employed. The wheel revolves with immense velocity, and streams of sparks of a green colour, arising from the combustion of the copper points of the radii of the wheel, are thrown sometimes over the cups of the instrument.

Mr. Sturgeon found that the division of the wheel into rays was not necessary, and that if a circular metallic disc be substituted for the spur wheel, as shown in Fig. 352, it will revolve equally well. In all these experiments it is important that the ends of the wires and surface of the metals which touch the mercury should be well amalgamated in order to ensure perfect contact.

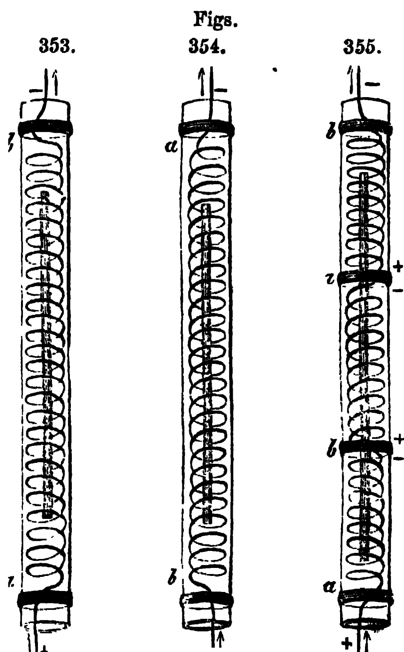
Fig. 352.



By altering the direction of the electrical current all the vibrations and rotations that have been just described are *reversed.*

(963) *Magnetizing Properties of the Voltaic Current.*—If the wire which connects the two extremities of a voltaic battery be plunged into fine iron filings, a considerable portion will be attracted and will remain attached to the wire as long as the current continues to circulate through it; on breaking the circuit, the filings will immediately drop off. If small steel needles be laid across the wire, they

will also be attracted, and on removing them they will be found to be permanently magnetized. The voltaic current is thus seen to possess the power of decomposing the natural Magnetism of magnetic bodies, in a manner precisely similar to magnets themselves. From what has been already said, it will appear evident that in order to give the current its full efficiency, it should be allowed to pass transversely round the iron or steel; it should surround it in the form of a helix. Here again we find the polarity given to the needle to depend on the direction of the turns of the helix. If it be a right-handed spiral (Fig. 353), the N. pole is always formed at the end at which the current enters, that is, on the positive side; if it be a left-handed helix (Fig. 354), the bar acquires at this end, a southern polarity. If the wire be twisted round the tube in such a manner as to form reverse contrary helices following one another, then the needle is magnetized with "consecutive poles" (807) at the junctions of the helices, each helix acting as if it were alone. If the helix be constructed in such a manner that it turns alternately from the right to the left, the needle will not be found to have acquired any permanent polarity. The magnetizing power of the voltaic current is exerted instantaneously, the steel bars acquiring the utmost Magnetism they are capable of receiving the moment the circuit is completed. This instantaneous breaking down of the resistance offered by the coercitive force of the bar is a phenomenon of a very remarkable character. We have in a previous chapter (828) described the application of the helix to the magnetizing of large steel bars by Elias of Haarlem. This method has been compared by Frick (*Annual Report of the Progress of Chemistry*, 1849), with that of the touch (819), an electro-magnet being used; on the whole he prefers the latter. By employing, however, the band spiral (828) recommended by Böttger, a 6-lb. bar of very hard cast steel was magnetized to satu-

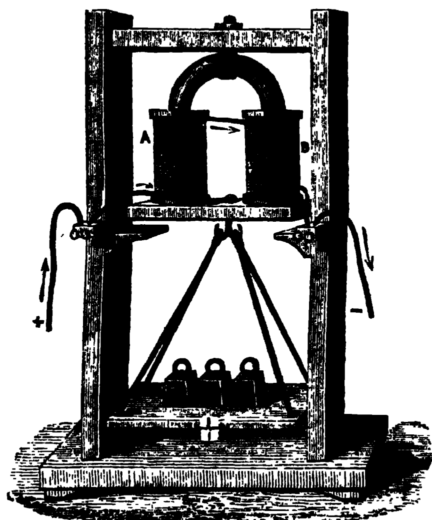


Figs. 353. 354. 355.

ration as completely as it could have been by any known process of communicating permanent Magnetism, merely by passing the spiral once backwards and forwards along the bar.

(964) *Electro-Magnets.*—When bars of soft iron are submitted to the influence of the voltaic current, they acquire a very high degree of Magnetism, but the *coercitive* force, that is, the force in a magnetic substance which opposes the separation of the two magnetic fluids, and their recombination when separated, being, in iron, almost inappreciable, the Magnetism is only temporary, the bar returning nearly to its normal state the moment the current ceases to pass through the enveloping helix; we say *nearly* to its normal state, because if the iron be not perfectly pure it always retains a certain amount of Magnetism. Fig. 356 shows the ordinary arrangement of the horse-shoe electro-magnet. The copper wire, which for large bars should be very stout and well covered with silk, is wound a a great number of times round the two arms, so as to form two bobbins, A and B. It must turn in the same direction round each bobbin, in order that the two extremities of the bar should acquire opposite polarities; the S. pole being formed on the side at which the current enters, and the N. pole on the opposite side. The power of the electro-magnet varies with the size of the iron cylinder, with the intensity of the current, and with the length and thickness of the copper wire. With regard to the thickness of the iron bar, the power of the electro-magnet to deflect a magnetic needle, has been found by Dub to be proportional to the square root of the diameter of the cylinder, and its lifting power in proportion to its simple diameter. Instead of coiling the wire round the bobbins in one continuous length, which is known to diminish considerably the influence of the current, it is better that the total length of wire intended to be used should be cut into several portions, each of which, covered with silk or cotton, should be coiled separately on the iron; the ends of all the wires are then collected into two separate parcels,

Fig. 356.



and made to communicate with the battery, care being taken that the current shall pass along each wire in the same direction. A powerful bar electro-magnet was constructed some years ago under the direction of Mr. Faraday, for the magnetic observatory at Woolwich. The helix was 27 inches long by $2\frac{3}{8}$ inches internal diameter; it had 4 coils of No. 7 copper wire covered with tape; their lengths being 108 feet 10 inches, 120 feet, 129 feet 7 inches, and 143 feet; in all 501 feet 5 inches; and they were arranged with bars and clamps so as to admit of using one or more of the helices variously combined. The soft iron core was 28 inches long by $2\frac{5}{8}$ inches in diameter, and there were 2 other cores, each $12\frac{1}{2}$ inches by $2\frac{3}{8}$ inches, for magnetizing a steel bar placed in the coil between them. A horse-shoe electro-magnet of extraordinary power was constructed in the year 1830, for the Faculty of Sciences, at Paris, by M. Pouillet. It consisted of two horse-shoes, the ends of the branches of which were presented to each other, the bands being turned in contrary directions. The superior horse-shoe was fixed in the frame of the apparatus, the inferior being attached to a cross piece which slided in vertical grooves formed in the sides of the frame. To this cross piece a platform was suspended in which weights were placed, by the effect of which the attraction which united the two horse-shoes was at length overcome. Each horse-shoe was wrapped with 10,000 feet of copper wire, and they were so arranged that the poles of contrary names should be in contact. With a current of moderate intensity, this apparatus supported a weight of many tons.

(965) In *Sturgeon's Annals of Electricity*, vol. vi., the three following electro-magnets are described. The first is the contrivance of Mr. Richard Roberts; its peculiarity consists in the great extent of the area of the face, on the surface of which a series of grooves are formed, into which the conducting wire is coiled. The magnet is $2\frac{7}{16}$ inches thick, and $6\frac{5}{8}$ inches square on its face, into which are planed (at equal distances from each other across its surface) 4 grooves, $1\frac{1}{4}$ inch deep, and nearly $\frac{3}{8}$ of an inch broad. Into these grooves was coiled, three-fold deep, a bundle of 36 copper wires (No. 18), wrapped with cotton tape, to prevent contact with the iron, the wires having no insulation from each other. The magnet, with the conducting wire, weighed 35lbs. The armature was $1\frac{1}{2}$ inch thick, and the same size as the magnet on the face; its weight was 23lbs. The upper side of the iron, which constituted the magnet, was formed into an eye or bow, by which the whole was suspended; and a similar bow was formed on the back of the armature, to which the weight scale was attached. This electro-magnet,

when excited by a battery of 8 pairs of Sturgeon's cast iron jars, is reported to have sustained the enormous weight of 2950 lbs. (*Sturgeon's Annals*, vol. vi. p. 168), which is nearly double the weight which the author's large magnet, the weight of which is about 112lbs., will sustain with any battery that has been tried.

The second is that of Mr. Joseph Radford. Its peculiarities consist in the convoluted figure of its face, and in the unusual arrangement of its poles, both of which are on the same convoluted strip of iron, one pole occupying the whole length on one edge, and the other the whole length of the opposite edge. Its diameter is 9 inches, and it weighs, with its copper coil, 18 lbs. 4 oz. The keeper, or armature, weighs 14 lbs. 4¾ oz. The depth of the convoluted groove, or recess, is ⅜ of an inch, and ¼ of an inch wide. The width or breadth of the metal between the grooves is ½ an inch; the thickness of the magnet is 1 inch at the outside edge, and about ⅝ in the centre. When excited by a battery of 12 of Sturgeon's jars, this electro-magnet is stated to have sustained 2500 lbs. avoirdupois; it is, therefore, in proportion to its weight, much more powerful than Mr. Roberts's magnet.

The third electro-magnet alluded to (vol. vi. p. 231.) is that of Mr. J. P. Joule, and is shown in Fig. 357. *B B* are two rings of brass, each 12 inches in exterior diameter, 2 inches in breadth, and 1 inch in thickness; to each of these, pieces of iron are affixed, by means of the bolt-headed screws, *s s*, &c.: 24 of these are *grooved*, and fastened to the upper ring; 24 are plain, and affixed to the lower ring. A bundle, *W W*, consisting of 16 copper wires (each of which was 16 feet long, and $\frac{1}{20}$th of an inch thick), covered with a double fold of thick cotton tape, was bent in a zig-zag direction about the grooved pieces. Fig. 358 represents the method adopted for giving the electro-magnetic ring a firm and equable suspension: *a a* are hoops of wrought iron, to each of which 4 bars of the same metal are riveted, and welded together at the other end into a very strong hook. The hoops are bound down to the brass rings by means of copper wires. The weight of the pieces of grooved iron was 7·25 lbs., and that of the plain pieces 4·550 lbs; and when excited by 16 pairs of the cast-iron battery, arranged into a series of 4, a weight of 2710 lbs. was suspended from the armature, without separating it from the electro-

Fig. 357.

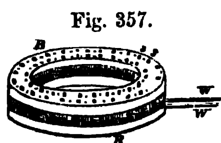
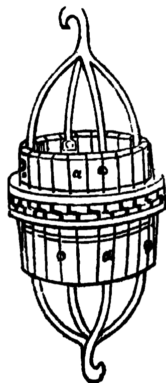


Fig. 358.



magnet; and Mr. Joule thinks, that by the use of some precautions, which have occurred to him since making his first experiments, the actual power will be very considerably augmented.

It has been mentioned that when very soft iron is employed in the construction of the electro-magnet, its Magnetism nearly disappears, when the voltaic current ceases to flow through the helix surrounding it. It was, however, discovered by the late Dr. Ritchie, that there are other circumstances which modify the retaining power; the most remarkable of which is the *length of the magnetic circuit.* When the electro-magnet is very short, and the poles near each other, the retaining power is exceedingly small; when the magnet is very long, the retaining power is very great, the reason of which appeared to Dr. Ritchie to be this (*L. & E. Phil. Mag.* vol. iii. p. 123.) the molecules of the electric fluid, acting on each other with the same force, will obviously return to their natural position most rapidly when the length of the circuit through which the action takes place is diminished. If it be diminished till the coercitive force of the iron be overbalanced by the tendency of the molecules to return to their natural state of equilibrium, from which they have been forced by the action of the conducting wire, the electro-magnet will lose all its retaining power.

Another singular fact discovered by Dr. Ritchie was, that a *short* electro-magnet, though its lifting power be very considerable, is incapable of inducing permanent Magnetism on an unmagnetized horse-shoe of tempered steel; while an electro-magnet of 4 feet in length, though of no greater lifting power than the small one, is capable of inducing a very considerable permanent effect. It was likewise found by Dr. Ritchie that a bar electro-magnet, 4 feet long, which scarcely retained any power when its connexion with the battery was broken, on being *re-connected* with it, in the *same* direction as before, was *rapidly* converted into a powerful magnet; but after being removed, and its wires now connected with the opposite poles, it required a long time to convert it into a magnet of much inferior power, as if the atoms of Electricity, having been first put in motion in one direction, are afterwards more easily turned in that direction than in the contrary.

(966) It was first noticed by Professor Page, of Philadelphia, (*Silliman's Journal*, 1837), that during the act of sudden magnetization of a bar of iron, a peculiar sound is elicited. This phenomenon has since been studied by Marrian, Joule, Grove, Beatson, and other electricians. The sound is best observed by resting the end of a long iron bar, surrounded with a coil of covered copper wire, on a sounding board; it thus becomes a musical note, and is distinctly

audible throughout a large room. It is heard both on magnetizing and demagnetizing the iron, that is, on making and on breaking contact between the coil and the battery; but it is louder in the latter case than in the former. By suspending an iron bar so that it could vibrate freely, and circulating the voltaic current by a wire so as not to touch the bar, and breaking and renewing battery contact rapidly, Mr. Beatson elicited sounds as loud and distinct as those from a small bell; he found, moreover, that similar though feeble tones were produced by passing an intermitting current from a set of 10 of Smee's battery, through a brass wire $\frac{1}{50}$th of an inch in diameter, stretched across a sounding board, and from an iron wire simply suspended without any tension, with each end dipping into a mercury cup. Professor Page succeeded in producing the *various notes in the scale* by carefully suspending steel bars within a series of coils, and breaking the galvanic current at the rate of five or six thousand times per minute by a revolving apparatus placed in an adjoining room. These effects are caused by a molecular disturbance of the particles of the metal by the action of the galvanic current, as has been well shown by M. Wertheim (*Comptes Rendus*, July 22nd, 1844). It is strikingly illustrated by an experiment arranged by Mr. Grove, in which a glass tube, open at both ends, but protected along its length with a copper jacket, is filled with water, in which is suspended powdered magnetic oxide of iron. On looking through the tube at distant objects, a considerable portion of the light is intercepted by the heterogeneous arrangement of the particles of the oxide; but on passing a current through a coil placed round the tube, these particles assume a symmetrical character, and much more light is transmitted. Mr. Beatson has shown (*Elect. Mag.* vol. ii, p. 295) that, at the moment the sound is produced, the metal undergoes a sudden expansion; in the case of an unannealed iron wire, amounting to about $\frac{1}{2000}$th of an inch, and on interrupting the circuit a similar sudden contraction takes place; this expansion and contraction is independent of that produced by the heating power of the current, as was proved by the fact of its taking place *after* the current had developed the total expansion which its heating power was capable of producing. Mr. Beatson also succeeded in eliciting distinct intonations from an iron wire by means of the discharge of a Leyden Jar; and we have frequently successfully repeated the same experiment.

(967) An ingenious piece of apparatus was invented by the late Dr. Ritchie for illustrating the induction of Magnetism on soft iron. It is shown in Fig. 359, where a bar of iron is represented covered with a helix of insulated copper wire and mounted horizontally on

a wire, the extremity of which is finely pointed, so as to allow the bar to rotate freely. The two ends of the helix are bent downwards so as just to dip into a small channel of mercury divided into two parts by a diaphragm of wood; one end of the wire dips into each division of the trough, and a sufficient quantity of mercury is poured into the trough to fill it, without however allowing the two portions to become united; the mercury in each division will be found to rise a little above the level of the partition by capillary repulsion. It will thus be immediately seen that on connecting the two cells of mercury with the two plates of a battery the current must pass through the helix enclosing the iron bar before the circuit can be completed, and that the iron will consequently become for the time magnetic. Now, suppose each end of the iron bar to be opposed to the pole of a powerful steel bar magnet, an opposite pole on each side, and suppose the connexions with the battery to be made so that the N. pole of the iron bar is formed opposite to the N. pole of the steel bar, then as a necessary consequence, the opposite end of the iron bar will be a *south* pole, and will be opposed to the S. pole of the steel bar; *repulsion* will accordingly take place on each side, and the iron bar will move through half a revolution. Here the wires of the helix surrounding it pass over the wooden partition, and dipping into the opposite cells of mercury, the polarity of the bar becomes reversed and so on, the bar soon revolving with great rapidity in consequence of its polarity being reversed twice during each revolution. Sometimes the bar is arranged to rotate vertically as shown in Fig. (360.)

Fig. 359.

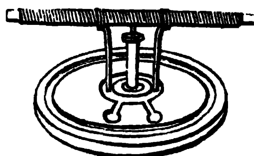
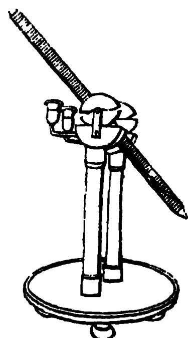
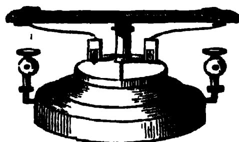


Fig. 360.



(968) In all these pieces of apparatus the employment of mercury is essential. Messrs. Knight have, however, devised a method of arranging the rotating magnet whereby the use of the fluid metal is dispensed with. A round plate of brass is divided by 2 small strips of ivory and the wires of the helix are terminated by 2 small metallic rollers which thus pass easily over the brass surface, contact being broken at the proper place by the ivory strips. Fig. 361 exhibits this useful modification of Ritchie's rotating magnet.

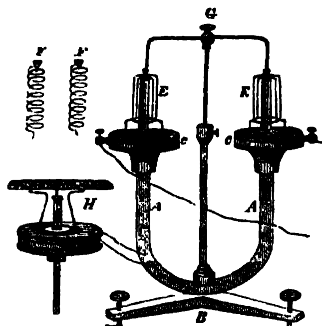
Fig. 361.



(969) In Fig. 362 a horse-shoe magnet is represented supported

on a tripod stand with levelling screws, in which state it is well adapted for exhibiting the rotation of coils, wires, helices, &c. *A A* is the magnet, *B* the tripod stand, *C C* two circular wooden cisterns for holding mercury, and capable of being adjusted at any required height by binding screws, *E E* are two light wire frames, *F F* two helices, *H* a Ritchie's rotating magnet; on the tops of the wire frames and helices are small cups to contain a drop of mercury, *G* is a piece of brass wire bent twice at right angles and terminated at each end by a fine point to dip into the globules of mercury: it can be raised or depressed without disturbing the general arrangement of the apparatus, as a simple inspection of the figure will show.

Fig. 362.



When the rotating magnet is set in action in this apparatus a loud humming noise and sometimes a loud musical sound is excited by the rapid vibratory motion assumed by the fixed magnet during the rapid revolution of the electro-magnet. This musical sound is best observed when the levelling screws of the tripod are placed on a mahogany table in the middle of a large room. For the electro-magnet *H* a simple coil of wire may be substituted, the rotation of which will be exceedingly rapid, its faces becoming alternately attracted and repelled by the poles of the magnet.

(970) In *Sturgeon's Annals of Electricity*, vol. iii., p. 426, will be found a description and engraving of an ingenious apparatus for exhibiting the simultaneous rotation in opposite directions of the permanent magnet and the electro-magnet. The current from the voltaic battery instead of going directly to the mercury flood in connexion with the electro-magnet, is made to enter two concentric troughs containing mercury, placed immediately under the former, communication between the upper and lower cups being established by means of wires; the electro and permanent magnet may thus be placed on one spindle, and the former being put in motion, it was found that the permanent magnet immediately commenced rotating in an opposite direction. This instrument was the contrivance of Mr. C. W. Collins.

(971) *Electro-Magnetic Engines.* — The prodigious force which electro-magnets manifest when excited even by a feeble current, and the power of annulling or reversing it in an instant, might seem to justify a hope of their affording a motive power as energetic and

more economical than the steam engine. An immense amount of inventive talent has been expended in attempts to realize this hope. These attempts have, however, shown (observes Dr. Robinson), that electro-magnetic engines can scarcely ever be a cheap or a very efficient source of power. Electricity is now known to have a definite mechanical equivalent. The zinc and acid required to produce it are more costly than the coal which will evolve *isodynamic* heat, and the hitherto contrived methods of converting Electro-magnetism into moving force, involve much more loss than the mechanism of the steam engine does in respect of heat. It may be added that the great magnetic force exists only in contact; on the least separation of the keeper it decreases rapidly, not merely because magnetic force follows the law of the inverse squares of the distance, but because that separation destroys in a very great degree the actual Magnetism of the magnet. It must, however, be kept in mind, that there are many cases, where economy and intensity are of less consequence than facility of application and convenience, in which therefore the electro-magnetic engines deserves a preference either for industrial purposes, and much more for the work of the experimental physicist, although its action may be more costly. In particular, the absence of all danger, and perfect quiescence when not put in action, and the capability of being moved to any locality where a couple of wires can be led from its battery, deserve special consideration.

(972) A series of experiments on the application of Electro-magnetism as a motive force, is described by Dumont (*Comp. Rendus*, August, 1851), and the following consequences deduced:—

1°. The electro-magnetic force, though it cannot yet be compared to the force of steam in the production of great power, either as it regards the absolute amount of power produced, or the expense, may nevertheless, in certain circumstances, be usefully and practically applied.

2°. While in the development of great power the electro-magnetic force is very inferior to that of steam, it becomes equal and even superior to it in the production of *small* forces, which may thus be subdivided, varied, and introduced into trades and occupations using but small capitals, where the absolute amount of mechanical power is of less consequence than the facility of producing it instantaneously and at will. In this point of view the electro-magnetic force assists, as it were, the usefulness of steam in the place of uselessly competing with it.

3° Other things being proportional, electro-magnetic machines, with direct alternating movement, present a great superiority of the power developed, over rotating machines, since, in the first, there are

no components lost, and with the same expense a much more considerable power is obtained than with rotating machines.

4° In machines of direct movement the influence of the currents of induction appears less considerable than in rotating machines.

(973) To describe in detail all, or the most ingenious even, of the electro-magnetic engines that have been invented during the last eighteen years would involve far too great an expenditure of time and space. We select a few that have been thought by their inventors worthy of being patented.*

* For the convenience of those who feel inclined to see and examine the descriptions of the numerous electro-magnetic machines that have been proposed by different experimentalists, a list of references to the periodicals containing some of the principal ones, is subjoined.

Sturgeon's Electro-magnetic Engine for turning Machinery. "Annals of Electricity," vol. i. p. 75.

Jacobi's valuable paper on the application of Electro-magnetism to the moving of machines, with a description of an Electro-magnetic Engine. "Annals of Electricity," vol. i. p. 408—419.

Mr. Joule's Electro-magnetic Engine. "Annals of Electricity," vol. ii. p. 122.

Mr. Davenport's Electro-magnetic Engine. "Annals of Electricity," vol. ii. p. 257.

The Rev. F. Lockey's Electro-magnetic Engine. "Annals of Electricity," vol. iii. p. 14.

Dr. Page on Electro-magnetism as a moving power. "Annals of Electricity," vol. iii. p. 554.

Mr. Joule's second Engine. "Annals of Electricity," vol. iv. p. 203.

Mr. Uriah Clarke's Engine. "Annals of Electricity," vol. v. p. 33.

Mr. Thomas Wright's Engine. "Annals of Electricity," vol. v. p. 108.

Mr. U. Clarke's Electro-magnetic Locomotive Carriage. "Annals of Electricity," vol. v. p. 304.

Jacobi on the "Principles of Electro-magnetical Machines." *Report of the Meeting of the British Association*, Glasgow, September, 1840. "Annals of Electricity," vol. vi. p. 152. (This is a most valuable paper, and is well deserving of attentive study.)

Mr. Robert Davidson's Electro-magnetic Locomotive. *Engineers' Magazine*, &c. Part 14, p. 48.

Mr. Taylor's Engine. *Mechanics' Magazine*, vol. xxxii. p. 694.

Mr. Watkins's Electro-motive Machine. *Phil. Mag.*, vol. xii. p. 190.

An Inquiry into the possibility and advantage of the application of Electro-magnetism as a moving power, by the Rev. James William M'Gauley. *Report of the Proceedings of the British Association for the Advancement of Science*, Dublin, 1835.

"Experiments and Observations on the Mechanical Powers of Electro-magnetism: Steam and Horses. By the Rev. Dr. Scoresby. *Phil. Mag.*, vol. xxviii. p. 448.

Dr. Kemp's Patent for a new Method of obtaining Motive Power by means of Electro-magnetism. *Repertory of Patent Inventions*, Feb. 1852.

Hansen's Electro-magnetic Engraving Machine. *Athenæum*, June 17, 1854.

A new Electro-magnetic Engine, invented by M. Marie Davy. *Comptes Rendus*, May 15, 1854; and *Phil. Mag.*, vol. vii. 1854.

(974) In *Silliman's Journal*, for April, 1837, there is a notice of a rotative engine, invented and patented by Mr. Thomas Davenport of Brandon in the county of Rutland, and State of Vermont, United States. The following is a general outline of its construction: The moving part is composed of 2 iron bars, placed horizontally, and crossing each other at right angles; they are covered with insulated copper wire, and sustained by a vertical axis; proper connexion with the voltaic battery being made in the usual manner. Two semicircles of strongly magnetized steel form an entire circle, interrupted only at the two opposite poles; and within this circle, which lies horizontally, the galvanized iron cross moves in such a manner, that its iron segments revolve parallel, and very near to the magnetic circle, and in the same plane. Its axis, at its upper end, is fitted by a horizontal cog wheel to another and larger vertical wheel, to whose horizontal axis the weight is attached, and raised by the winding of a rope. By the galvanic connexion, these crosses, and their connected segments are magnetized, acquiring N. and S. polarity at their opposite ends; and being thus subjected to the attracting and repelling force of the circular fixed magnets a rapid horizontal movement is produced, at the rate of 600 revolutions in a minute, when a large calorimotor is employed. The movement is instantly stopped by breaking the contact with the battery, and then reversed by simply interchanging the connexion of the wires of the battery with those of the machine, when it becomes equally rapid in the opposite direction. Another machine, composed entirely of electro-magnets, both in its fixed and revolving members, is also described.

(975) In a subsequent number of the same Journal, it is stated that the proprietors had been engaged in experiments on magnets of different modifications, as well as on the proper distance between the magnetic poles of the circle; that they had entirely altered the form and arrangement of the magnets, greatly increasing thereby the energy of the machine. The use of magnets in the form of segments of a circle, was discontinued, and horse-shoe formed magnets substituted; the poles being changed once in every 3½ inches of the circle. On this arrangement, a machine with a wheel 7 inches in diameter, elevated 90 lbs. 1 foot per minute, and performed about 1200 revolutions in the same time. It is also stated that the proprietors were engaged in constructing a machine with a motive wheel of about 2½ feet in diameter, from which, it was expected, that sufficient power to propel a Napier's printing press (requiring a 2-horse power), would be obtained.

(976) In 1838 Captain Taylor obtained a patent for an electro-

magnetic engine in the United States; and on November 2nd, 1839, he patented the same engine in England. In the London *Mechanics' Magazine*, vol. xxxii. p. 694, there is a full description and drawing of this engine, a working model of which was for some time exhibiting in the Colisseum, in active operation, turning to the wonder and admiration of thousands, articles in wood, ivory, and iron. Referring to the above periodical for a detailed description of this engine, we shall confine ourselves to the peculiar principle of its action, as explained by Mr. Taylor. "The generality of the plans which have been hitherto devised for obtaining a working power from Electro-magnetism, have depended on taking advantage of the *change of polarity*, of which masses of iron fitted as electro-magnets are susceptible, so as to cause them alternately to attract and repel certain other electro-magnets, brought successively within the sphere of their influence, and thus to produce a continuous rotatory movement; and the failure of these attempts is owing to the difficulty, if not impossibility, of accumulating power by such means. Instead of this, Mr. Taylor employs as his prime movers a series of electro-magnets, which are alternately and almost instantaneously magnetized and demagnetized, without any change of polarity whatever taking place, and certain other masses of iron or electro-magnets, are brought successively under the influence of the said prime movers when in a magnetized state, which latter are demagnetized as soon (or nearly so), and as often as their attractive power ceases to operate with advantage; or in other, and perhaps plainer words, his invention consists in letting on, or cutting off, a stream of the electric fluid in such alternate, quick, and regular succession, to and from a series of electro-magnets, that they act always attractively or positively only, or with such a preponderance of positive attraction, as to exercise a uniform moving force upon any number of masses of iron or magnets, placed so as to be conveniently acted upon." The power of the machine constructed on this principle, which was exhibiting at the Colisseum, was small, certainly much below that of a single man. Mr. Henley, however, afterwards constructed a very large engine on the same principle, which did some work, though at an enormous expense, the battery employed containing 13 cwt. of metal.

(977) It appears from a letter in the *Phil. Mag.*, (vol. xv. p. 250,) from Professor P. Forbes, of Aberdeen, and also from a communication from Mr. Robert Davidson to the *Mechanics' Magazine*, (vol. xxxii. p. 63,) that the latter individual had anticipated Mr. Taylor in the principle of his machine, having in 1837 employed the electro-magnetic power in producing motion by *simply suspending the*

Magnetism without a change of the poles: "so close," says Mr. Davidson, "is the resemblance between Mr. Taylor's machine and one of mine, that, independently of the frame work, I believe the chief differences are, first, that the circumference of Mr. Taylor's revolving disc is composed of alternate parts of copper and ivory, while the circumference of mine is composed of alternate parts of copper and box-wood; and second, that in Mr. Taylor's machine the armatures appear to be sunk to about half their depth in the periphery of the wheel to which they are attached, while in mine they are sunk their whole depth, so as to be *flush* with the cylindrical surface."

(978) In the *Practical Mechanics' and Engineers' Magazine* for November, 1842, there is a full account and drawing of a large electro-magnetic locomotive constructed by Mr. Davidson, and tried on the Edinburgh and Glasgow Railway. The carriage is 16 feet long and 6 feet broad, and weighs above 5 tons, including batteries, magnets, &c. The electro-magnets are not one solid piece of iron, nor are they rounded behind. Each of the side parts or arms is constructed of 4 plates of soft iron put together, so as to form as it were a box for the sake of lightness. The arms are 25 inches long, and joined together behind by plates of iron. Their rectangular poles measure 8 by 5 inches, and at their nearest points are only about 4 inches asunder. The coils with which they are surrounded do not consist of a single copper wire, but of bundles of wire wrapped round with cloth to insure insulation. According to Mr. Davidson's first arrangement, these magnets were placed so that their poles were nearly in contact with the revolving masses of iron in their transit; but so prodigious was the mutual attraction that the means taken to retain the magnets and iron in their assigned position were insufficient. They required to be more firmly secured, and their distances had to be somewhat increased, which perhaps contributed very materially to the failure of the machine, which when put in motion on the rails travelled about 4 miles an hour only, thus exhibiting a power less than that of a single man, who on a level railway could certainly move a carriage of this weight at as great a velocity.

(979) In 1838, Professor Jacobi, of St. Petersburg, at the expense of an imperial commission, tried the grand experiment of propelling a boat by the agency of Electro-magnetism. The vessel was a ten-oared shallop, equipped with paddle wheels, to which rotatory motion was communicated by an electro-magnetic engine. The boat was 28 feet long and 7½ feet in width, and drew 2¾ feet of water. In general there were 10 or 12 persons on board, and the voyage was continued (on the Neva), during entire days. The

difficulty of then managing the batteries, and the imperfect construction of the engine were sources of frequent interruption, and could not be well remedied on the spot. After these difficulties were in some degree removed, the professor gives as the result of his experiments, that a battery of 20 square feet of platinum will produce power equivalent to 1 horse: but he hoped to be able to obtain the same power with about half that amount of battery surface. The vessel went at the rate of *four miles* per hour, which is certainly more than was accomplished by the *first* little boat that was propelled by the power of steam. In 1839, Jacobi tried a second experiment in the same boat; the machine, which was the same as that used on the previous occasion, and which occupied little space, was worked by a battery of 64 pairs of platinum plates, each having 36 square inches of surface, and charged according to the plan of Grove with nitric and sulphuric acid. The boat, with a party of 12 or 14 persons on board, went against the stream at the rate of 3 miles an hour.

(980) Professor Page, of America, who has greatly distinguished himself by his researches in this department of science, has invented an electro-magnetic engine, the fundamental principle of which is thus described (*Silliman's American Journal*, Nov. 1850): "It is well known that when a helix of suitable power is connected with the poles of a battery in action, an iron bar within it will remain held up by the induced Magnetism, although the helix be placed in a vertical position; and if the bar be partly drawn out of the helix by the hand, it goes back with a spring when the hand lets go its hold. This power—the action of the helix upon the metallic bar within it—is the power used in Page's engine. The power, when a single coil is used, has its points of greatest and weakest force, and in this condition is objectionable. But by making the coil to consist of a series of short independent helices, which are to be brought into action successively, the metallic rod is made to pass through the coil and back again, with great rapidity and with an equable motion. In all the engines hitherto used there is a loss of power at the instant of the change of current, owing to the production of a secondary current, moving in the opposite direction, and to this loss is owing the fact that these engines cannot be rendered available. Professor Page had in view the obviating of this difficulty when he commenced his investigations. He exhibited one of his engines of between 4 and 5 horse-power at the Smithsonian Institute, the battery to operate which was contained within the space of 3 cubic feet. It was a reciprocating engine of 2-feet stroke, and the whole, including the battery, weighed about 1 ton. Page states that the consumption of 3 lbs. of

zinc a day would produce a 1 horse-power. Joule's estimate is widely different; he calculates that in an electro-magnetic engine, constructed most favourably to prevent loss of power, the consumption of zinc per 24 hours to produce 1 horse-power is in a Grove's battery 45 lbs., and in a Daniell's battery 75 lbs.

(981) By an extended application of the force which attracts a mass of iron within an electro-magnetic helix, Hankel also attempted to produce a motive power; his investigations established the important practical law "*that this force is as the square of the power of the current.*" Fessel has also described an engine constructed on the same principle (*Bibliothèque Universelle de Genèva*). His model is formed of two helices placed end to end in a horizontal position. They serve to conduct the current always in the same direction, but in such a way that it traverses alternately each of the two helices, and consequently only one at a time. In the interior of the helices is a bar of iron which is alternately attracted from the one into the other by constantly maintaining the same polarity, and which thus executes a motion backwards and forwards. To the two extremities of the bar are fixed two slender horizontal shanks of brass, which rest upon two pulleys attached to the two extremities of the apparatus, and which thus support the whole weight of the iron. One of these shanks sets a wheel in motion; a commutator is moved by an eccentric, by means of a directing rod which is placed so as to be able to make the machine move backwards and forwards as in steam vessels. In his later machines, Fessel has replaced the pulleys by oscillating shanks of metal rod, similar to the oscillating cylinders of steam engines.

Fig. 363.

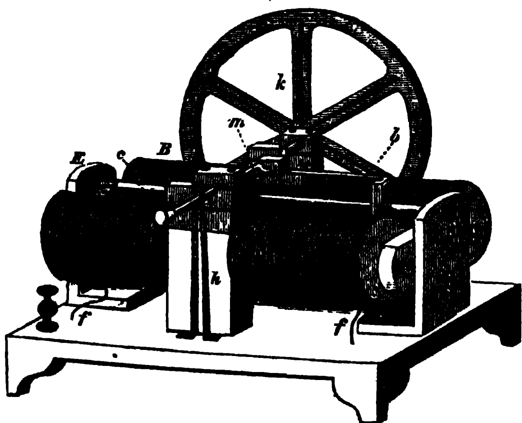


Fig. 363 represents a small working model of an electro-magneto-motive engine constructed by Mr. Bain, with some few improvements by the publishers of this work. On to a stout mahogany board are fixed the brass uprights *E E*; to these are attached the electro-magnets *A B*, covered with stout wire; through the upper part of these uprights, and above the

magnets, the two ends of the steel spindle *c* work; this spindle carries about its centre an iron bit, which is alternately attracted by the two magnets *A* and *B*, but prevented from absolute contact by pieces of paper; another spindle, *m*, at right angles with *c*, and supported by the uprights, *h h*, carrying at one end the fly-wheel, *k*, and on the other a small pulley, is cranked in the centre and connected with *c* by the spring and hook *b*. At *h* are seen two brass springs bearing lightly on the spindle, which is divided in the middle by a small piece of ivory, so that one only is in contact at the same time. The connexions are formed thus: one termination of the electro-magnet, *A*, is connected to one of the upright springs bearing on the spindle, and the other termination to the binding screws seen at the end of the board. The one termination of the electro-magnet *B* is connected with the other spring, and the other extremity to the same binding screw to which one end of *A* was attached, the remaining binding screw being in connexion by means of a wire with the brass box in which *m* works. The working of this machine is greatly assisted by two spiral springs fixed underneath the board attached to the moving bit. The whole arrangement performs extremely well, and no doubt if made on a large scale would be very powerful.

(982) Mr. Henley gives the following descriptions of two electro-magnetic engines, constructed by him for Mr. Talbot and Professor Wheatstone:—

"Mr. Talbot's engine consisted of 6 powerful horse-shoe electro-magnets, placed in a line with their poles upwards; to each magnet was adapted an armature, to which was affixed a jointed arm; in the centre of the armature was a hole which was fitted to a 6-throw crank, the throws set at an angle of 60° with each other, the currents acting on the magnets in succession from 1 to 6; at the time of breaking at 6 it commences again at 1: contact is made when the armature is at a small distance from the magnet, and is continued till it reaches it; at this moment contact is broken and made with the succeeding one; the connecting rod playing through the hole in the armature allows the crank to pass down; when it remains stationary on the poles of the magnets a piece of paper prevents adhesion. There is a knob at the end of the connecting rod, by which it lifts the armature in one position, and is pulled in the other. In this machine the magnet acts when the crank is in the very best position, and were it not for the additional friction from the great number of rubbing parts, it would certainly be the best form of machine. On the shaft is mounted an A shaped frame, and at one end carries a heavy fly wheel, and at the other a contact-breaking

apparatus, which consists of a wheel and 6 levers, the points of which dip in mercury."*

The original of Professor Wheatstone's machine consists of a brass ring, within which are placed 8 magnets; an eccentric wheel revolves within, the longest radius of which passes close to each magnet successively, following the current as it were, which acts on each magnet a little in advance of the wheel; the break piece, which is stationary, is made of a piece of ivory, into which are let 8 pieces of brass; the shaft which passes through this without touching, carries a spring which presses on the break piece. The shaft and frame work is in connexion with one pole of the battery, one end of the coil on each magnet, and the other end of each with its corresponding piece of brass; the shaft also carries a fly-wheel and pulley to transfer the power. If there were a hundred magnets, of course the same battery would be sufficient, as they only act one at a time.

Mr. Henley has also constructed a machine which works a lathe, it is made with 3 horse-shoe magnets, with their poles upwards, the bent parts crossing each other; a bolt passes through them and holds them firmly to a base: within the poles revolves a soft iron cross; one magnet acts at a time, but the cross is attracted continually. The cross is suspended by 4 stout brass columns. At first there were but 2, it was found necessary, however, to add 2 more to resist the strain of the magnets, as the poles are curved, and the cross passes very close: there is a piece of apparatus to stop it immediately—it is a lever, which makes contact with one of the magnets independent of the break piece.

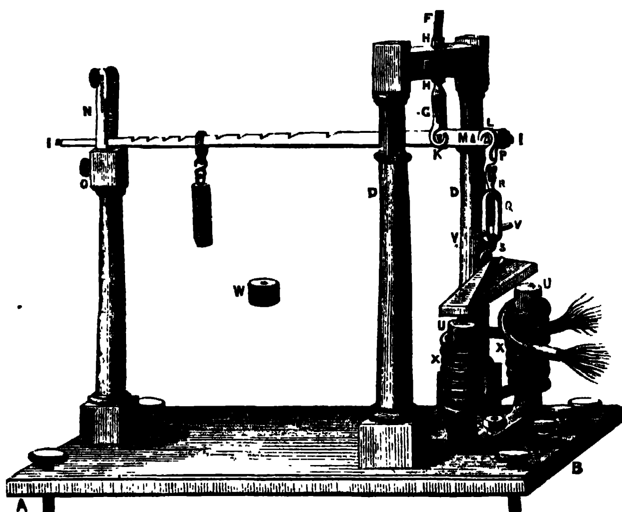
(983) Electro-motive power has been applied very successfully by M. Gustave Froment of Paris, who has obtained so high a celebrity for the construction of accurate mathematical and astronomical instruments. We had prepared a description of one of the large one-horse-power machines of this ingenious mechanician from the "Elements de Physique" of M. Pouillet; but having since been informed by the inventor that the description is inaccurate, and moreover that he had been obliged to abandon the use of the machine for giving motion to his lathes and planing machines, on account of

* This engine was 3 feet 6 inches long, and 2 feet 6 inches wide, but its power was not equal to the expectations that were formed of it; when excited by a Grove's battery, consisting of 4 cells with double plates of zinc 9 inches by 6½, platinum plates 9 inches by 5½, excited by diluted sulphuric acid 1 to 4, and concentrated nitric acid, Mr. Henley drove with it a lathe in which he turned a gun-metal pulley 5 inches in diameter, but in three quarters of an hour the battery was quite exhausted. This machine, it will be observed, was something more than a *model*.

the great expense of the battery, which amounted to 20 francs per day, we have not thought it worth while to have fresh drawings made of the machine. M. Froment states, however, that for delicate work, such as for giving motion to dividing instruments, polishing apparatus, &c., he finds electro-magnetic power very valuable as a mechanical agent, and constantly employs it in his workshop.

(984) *Hearder's Magnetometer.*—This simple but useful apparatus designed by its author for ascertaining the conditions which modify the development of Magnetism in iron by the action of electrical currents, is shown in Fig. 364.

Fig. 364.



A B is a strong base of wood. about 4 feet long and 1 foot wide, to which are attached 4 levelling screws. D D are two strong iron uprights, firmly screwed into the base, and connected at the top by a stout iron cross piece E, having a hole in the centre through which passes the screwed tail F, of a strong double suspension hook G. Two iron nuts, H H, serve to fix the suspension hook at any height. I I is a light and delicate, but strong steel yard, being graduated on one side to correspond with the distance between the knife edges K and M; these are respectively 1 and 2 inches apart. Different weights, from 1 oz. to 16 lbs., are applied on the long arm, according to the power to be measured. N is a rest to support the long arm of the lever, and is capable of being adjusted to any height by a tightening screw in

the hollow socket O. P is another suspension hook, upon which is hung the connecting piece Q; which, by means of the long screw R, and swivel hook S, will admit of elongation or contraction without altering the parallelism of the keeper T, of the magnet U U. The magnet is secured to the stand by a lever, which passes through a hole in the fork, and through two iron plates, one above and the other below the stand, the whole being tightened by a screw nut from below. V V are two projecting studs, which serve to support the cylindrical counterpoise weights W (seen in another part of the figure) which are made of lead cast with a hole in the centre, to allow of their being placed on, over the connecting piece Q, these weights are adjusted so as to exactly balance the long arm of the lever. A variety of magnets, differing in their shape and relative proportions, may be used in the place of N N: an extremely useful arrangement is represented in the figure. U U is a wire rope composed of 24 strands of No. 16 copper wire, each 12 feet long.

These are all previously covered with cotton and thickly varnished with sealing wax, so as to render them perfectly independent of each other. They are then twisted together into a rope, by which means every strand bears the same relative position on the magnet. The whole rope is again covered with tape and varnished. It is then coiled upon the magnet, as represented in the figure, the ends being left loose, and numbered by attaching tickets to them. The value of this arrangement will be seen by taking the two extremes of which it is susceptible. First, all the similar ends may be united in one by a binding screw at each end, thus forming one stout conductor, 12 feet long and 24 strands thick; or they may be united at dissimilar ends, so as to form one continuous length of 288 feet. A great variety of intermediate lengths and thicknesses can of course be formed, or the whole may be divided into independent conductors, carrying separate currents, either coincident or reverse. This arrangement will be found well adapted to determine the laws which govern a great variety of phenomena. For example, let it be required to ascertain the rate at which the magnetic development in iron proceeds, with known additions of exciting power. A small battery is attached to each wire, and the effect of each separately noted. The batteries are then added one after the other, and the difference between the actual and calculated effects can be thus ascertained. Again, the best mode of arranging wire upon a magnet, so as to obtain the greatest amount of power with a given quantity of wire and a battery of given dimensions, may be ascertained by taking any number of strands and uniting them in different lengths and thicknesses. The law of the resistance of wires and its relation to

electro-motive force may be investigated under a great variety of conditions, and the relative value of different voltaic arrangements for electro-magnetic purposes may be correctly examined. The practical magnetist will perceive a great variety of applications, of which the instrument is susceptible, in addition to those already mentioned.

(985) The following experiments with this instrument, having for their object to ascertain the rate of magnetic development in iron, by successsive additions of exciting elements of known power, applied through separate and independent coils, have been communicated by Mr. Hearder.* The 24 strands of wire upon the electro-magnet were separately tested by the same battery, and each was found to produce the same lifting power; 24 Smee's batteries were employed in separate cells, each having a platinized silver plate of 4 inches square, and 2 amalgamated zinc plates to correspond. The magnetizing power of each battery was first ascertained, and its value noted in lbs. Each battery had a single wire of the electro magnet appropriated to it, independently of the rest, and in each case the electro-motive force of the battery was less than the resistance of the wire, or, in other words, each battery excited more Electricity than the wire would carry. The batteries were numbered, and superadded in succession each to its own wire. The 1st column in the following table gives the distinctive number of the battery wire. The 2nd, the distinctive number of the battery. The 3rd, shows the value or exciting power in lbs. of each battery. The 4th, the calculated sum of the elements employed; and the 5th shows the actual effect upon the electro magnet:

TABLE I.

Showing the rate of magnetic development in iron, by successive known increments of exciting voltaic power, applied through separate and independent coils.

No. of wire.	No. of battery.	Value of battery.	Calculated sum of the elements employed.	Total weight sustained.
1	1	14½	14½	14½
2	2	18¼	32¾	42½
3	3	17¼	50	70½
4	4	13½	63½	94
5	5	15¾	79¼	111½
6	6	15	94½	125
7	7	14½	108¾	142

No. of wire.	No. of battery.	Value of battery.	Calculated sum of the elements employed.	Total weight sustained.
8	8	18½	127¼	155
9	9	17½	144¾	169
10	10	13½	158¼	174
11	11	15¾	174¼	186
12	12	15	189¼	195
13	13	14½	203¾	207
14	14	18¼	222	218
15	15	17¼	239¼	229
16	16	13½	252¾	236
17	17	15¾	268½	238½
18	18	15	283½	244½
19	19	14½	298	252
20	20	18¼	316¼	256½
21	21	17¼	333½	260
22	22	13¼	346¾	264
23	23	15¾	262½	267
24	24	15	377½	271

(986) By this table it appears that, up to a certain point, the increase of magnetic power goes on more rapidly than is equivalent to the value of the additional exciting element. Up to 7 elements there appears an average excess of about 31 lbs., but the proportion which this excess bears to the sum of the elements, appears to diminish rapidly after this point; and when about 12 or 13 are used, the excess almost disappears, and the total weight sustained is nearly equivalent to the united power of the batteries employed. After this point the production of power bears a decreasing ratio to the power employed, and this diminution of effect becomes more and more considerable towards the end, so that the last 5 elements scarcely produce an increase of effect equivalent to the value of one. Hence, it would appear, that a limit would somewhere be found to the susceptibility of iron to undergo magnetic induction. As the addition of each battery was in effect a mere extension of surface, the intensity of battery being the same, and as each wire presented the same resistance, an experiment was afterwards made with 12 voltaic elements, separately applied to 12 wires, and after ascertaining the amount of weight sustained, the 12 silver plates were united by one common conductor on one side, and the 12 zinc plates on the other, so as to make a single pair of twelve times the area, the wires of the electro-magnet still remaining attached, *but no alteration of effect was observed.* Some results analogous to the preceding were obtained from

the following experiments, in which the increase of surface was effected by immersing a single pair of larger size in acid, by successive equal portions, and connecting an extra wire with it for each successive portion immersed: the results are given in the following table :—

Table II.

Showing the rate of magnetic development in wire, by successive and equal additions to the surface of the voltaic element, and corresponding additions to the capacity of the transmitting coil.

No. of wire.	Inches immersed.	Value.	Calculated sum of the elements employed.	Total weight sustained.
1	1	11	11	11
2	2	11	22	25½
3	3	11	33	40
4	4	11	44	53
5	5	11	55	66
6	6	11	66	80

This table shews the same kind of difference between the increasing ratio of the resulting magnetic power, and that of the sum of the elements employed, estimated according to their individual value.

(987) *Application of the Magnetometer to estimate the Electro-motive Character of different Voltaic Arrangements.*—Three voltaic elements were constructed as nearly as possible alike in size and surface. 1st. A Grove's nitric acid battery, consisting of a platinum plate, 4 inches square, immersed in a suitable flat diaphragm, externally to which were a pair of corresponding zinc plates. 2nd. A Daniell's sulphate of copper battery, having a copper plate of 4 inches square, and a diaphragm and zinc plates similar to the 1st. 3rd. A Smee's battery of similar dimensions, but having its zinc plates equidistant with those of the other batteries, in order to place each arrangement under the same conditions, with the exception of the omission of the unnecessary diaphragm. 4th. A Smee's battery, with the zinc plates at the ordinary distance from the silver. These batteries were first tested as to the relative quantities of Electricity excited by each, by employing a short helix of large dimensions, consequently opposing little or no resistance, the wires being united so as to form a helix 12 feet long, and 24 wires in thickness. Secondly, they were tested for intensity, by uniting the wires end to end, so as to form a single wire of 288 feet in length, thus opposing great resistance. The results are given in the following table :—

TABLE, showing the comparative power of Grove's, Daniell's, and Smee's batteries, in relation to quantity and intensity.

INTENSITY.		QUANTITY.	
Grove	87	Grove	44
Daniell	43½	Daniell	12
Smee, No. 1, open	27½	Smee, No. 1, open	42
Smee, approximated plates	32	Smee, approximated plates	49

Thus, it appears, that nearly equal quantities of Electricity are excited by equal surfaces of Grove's and Smee's batteries, but that the electro-motive force or intensity of the nitric acid battery is rather more than three times that of Smee's. Daniell's arrangement holds an intermediate position with regard to intensity, but is deficient in quantity.

CHAPTER XIX.

MAGNETO-ELECTRICITY.

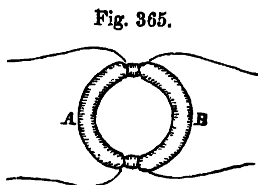
Electro-dynamic and Magneto-electric induction — Terrestrial Magneto-electric induction—Faraday's Researches—The Magneto-electric machine—Secondary currents—Electro-magnetic coil machines—The induction coils of Ruhmkorff and Hearder.

(988) *Electro-dynamic and Magneto-electric Induction.*—When a current of Electricity from a single voltaic pair is sent through a metallic wire, it induces a current of Electricity in a second wire forming a complete circuit and placed parallel to it, both at the moment when contact with the battery is made and when it is broken; but while the Electricity *continues* to flow through the first wire, no inductive effect on the second wire can be perceived. The direction of the induced current on breaking battery-contact is the reverse of that on making contact. In the former case it is in the *same* direction, and in the latter in the *reverse* of that of the inducing current. By arranging a length of about 200 feet of copper wire in a coil round a block of wood, and a second similar coil, as a spiral, between the coils of the first—metallic contact being everywhere prevented by twine—by connecting the ends of the second coil with a small helix formed round a glass tube in which was placed a common sewing needle, and then causing a current of Electricity from a voltaic battery to pass through the first coil, Faraday proved that the needle became a *magnet*, provided it was removed from the helix *before* battery contact was broken; if, however, it was allowed to remain, its Magnetism was entirely or very nearly destroyed. If the needle was introduced into the helix *after* battery contact had been made in the first coil, it acquired no magnetic properties unless it was allowed to remain till battery contact was broken, it then became a magnet, though with its poles in a contrary direction from the first, thus proving that it is only at the moment of making and breaking battery contact that a current of Electricity is induced in the second coil, and that the direction of the induced current is opposite in the two cases.

(989) If, instead of coiling the wires round a block of wood, they are arranged round a ring of iron as shown in Fig. 365, where *A* and

B represent the compound helices, being separated by about ½ an inch of uncovered iron, a current of Electricity from the battery sent through one helix *A*, induces a current in the second helix *B*, much more powerful than when the arrangement is made round wood, but only on making and breaking contact as before; if the battery be large, a minute *spark* may be perceived between charcoal points fastened to the ends of *B*, at the moment of making, and sometimes, though not often, on breaking contact with the battery, but never while a continuous current is passing through *A*.

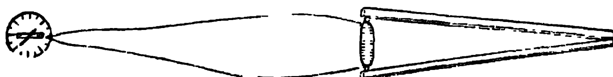
Fig. 365.



(990) To prove that the increased inductive power is occasioned by the iron and is not a common effect of metals, an arrangement of helices of copper wire may be wound round a hollow cylinder of thin wood or pasteboard, and the power of the induced current tested first with the helices alone; then, after inserting a bar of copper, lead, tin, or any other metal except iron, and perhaps nickel, in the axis of the cylinder, no effect beyond that of the helices alone will be found to be produced; but when a bar of soft iron is inserted, the power of the induced current will be found to be surprisingly increased.

(991) By the following beautiful experiment (*Ex. Resear.*, 36, 37), the property of *ordinary magnets* to induce electrical currents without the intervention of any galvanic arrangement, is clearly demonstrated. A long compound helix wound round a cylinder of pasteboard was connected with a galvanometer by two copper wires, each 5 feet in length; a soft iron bar was introduced into its axis; a couple of bar-magnets, each 24 inches long, were arranged with their opposite poles at one end in contact, so as to resemble a horse-shoe magnet, and then contact made between the other poles and the ends of the iron cylinder so as to convert it into a magnet, as shown in Fig. 366. By breaking the magnetic contacts, or reversing them, the Magnetism of the iron cylinder could be destroyed or reversed at pleasure. Upon making magnetic contact, the needle was deflected; continuing the contact, the needle became indifferent and resumed its first position; on breaking contact it was again deflected, but in the opposite direction; and then it again became indifferent; when

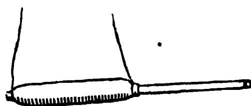
Fig. 366.



the magnetic contacts were reversed, the deflections were reversed.

In order to prove that the induced electrical current was not occasioned by any peculiar effect taking place during the formation of the magnet, Faraday made another experiment in which soft iron was rejected, and nothing but a permanent steel magnet employed. The ends of the compound helices being connected with the galvanometer, either pole of a cylindrical magnet was thrust into the axis, as shown in Fig. 367, the needle of the galvanometer was immediately deflected, but soon resumed its first position; on withdrawing the magnet a second disturbance of the needle took place, but in an opposite direction.

Fig. 367.



(992) When a powerful magnet is employed, induced electrical currents are evinced by the galvanometer, when the helix with its iron cylinder is brought near, but *without touching* the magnetic poles; and by experimenting with the large compound magnet belonging to the Royal Society,* Faraday was able to throw the needle of the galvanometer 80° or 90° from its natural position by placing the copper helix *without the iron cylinder* between the poles; and by using an armed loadstone capable of lifting about 30 pounds, he succeeded in *powerfully convulsing* the limbs of a frog by the induced electrical current.

(993) *Terrestrial Magneto-electric Induction.*—When a soft iron bar is held in the direction of the magnetic meridian, and inclined in the position of the *dip* of the needle, it becomes a temporary magnet, the lower end acquiring the properties of the N. pole; if the bar be inverted, its polarity is at the same time changed. Faraday took a soft iron cylinder, and having carefully deprived it of all traces of Magnetism by heat, he placed it in the axis of a coil of wire, the ends of which were connected with a galvanometer by wires eight feet long. The coil was held in the line of the dip, and then suddenly inverted; the needle of the galvanometer was immediately deflected, proving that a current of Electricity was evolved by means of the Magnetism of the globe; he afterwards succeeded in obtaining indications of Electricity *without the iron cylinder;* and by causing a circular plate of copper to rotate in a horizontal plane, electric phenomena were produced without any other magnet than the earth: when the plate was revolved in the same direction as the hands of a watch

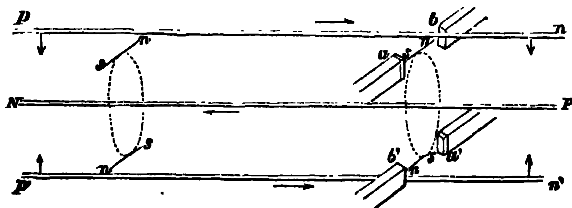
* This magnet is composed of about 450 bar magnets, each 15 inches long, 1 inch wide, and ½ an inch thick, arranged in a box so as to present at one of its extremities two external poles. It requires a force of nearly 100 pounds to break the contact of an iron cylinder ¾ of an inch in diameter and 12 inches long, put across the poles. It formerly belonged to Dr. Gowin Knight.

move, the current of Electricity was from the centre to the circumference; when in the contrary direction, the current was from the circumference to the centre.

(994) *A new electrical machine* was thus formed, differing remarkably from the common machine in the circumstance of the plate being a most perfect conductor, and in the absolute necessity of a good conducting communication with the earth. When the plate was revolved in the magnetic meridian no electrical effects were developed, and they became most powerful when the angle formed by the plane of the plate with the dip was 90°. It was likewise shown by Faraday that a current of Electricity is produced in a wire by merely moving it from right to left, or from left to right, over a galvanometer, and he states it to be a remarkable consequence of the universality of the magnetic influence of the earth, that scarcely any piece of metal can be moved in contact with others, either at rest or in motion with different velocities or in varying directions, without an electric current existing within them; further researches likewise proved that the current produced by the magneto-electric induction in bodies, is exactly proportional to, and altogether dependent upon their conducting power.

(995) By the aid of the diagram, Fig. 368, the relation between volta-electric and magneto-electric induction may easily be understood. Suppose an electrical current to be passing through the middle wire from *P* to *N*, this wire is surrounded at every part by *magnetic curves*, diminishing in intensity according to their distance from the wire, and which in idea may be likened to rings situated in planes perpendicular to the wire, or rather to the electric current within it. The dotted rings may represent the magnetic curves round the wire *N P*, and if small magnetic needles be placed as tangents to it, they will become arranged as in the figure. But if instead of causing the needles to be influenced by an electric current,

Fig. 368.

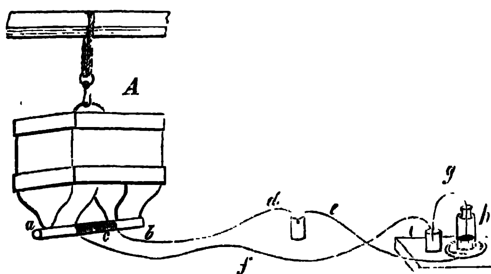


they are acted on by magnets, then in order that they shall take up the same position as before, the magnets must be placed as shown in the figure, the marked and unmarked poles *a b* above the wire being

in opposite directions to those *a′ b′* below it; in such a position, therefore, the magnetic curves between the poles *a b* and *a′ b′* have the same general direction with the corresponding parts of the ring magnetic curve surrounding the wire *N P* carrying the electric current. Now if a second wire *p n* be brought near the wire carrying the electric current, it will cut an infinity of magnetic curves in the same manner as it would the magnet curves if passed from above downwards between the poles, and the electric current induced in the wire will obviously be the same in both cases; if the wire *p′ n′* be carried up from below, it will pass in the opposite direction between the magnetic poles, but then the magnetic poles themselves are reversed, consequently the induced current is in the same direction as before; it is also for equally evident reasons in the same direction, if produced by the influence of the curves dependent on the wire.

(996) *Electric Spark from a Magnet.*—Faraday first obtained a spark from a temporary or electro-magnet in November, 1831; but the first person who obtained the spark from a natural or permanent magnet in this country, was Professor Forbes of Edinburgh; the experiment was made on the 13th of April, 1832, with a powerful natural magnet capable of supporting 170 lbs., presented to the University of Edinburgh, by Dr. Hope.* The arrangement of the apparatus is shown in Fig. 369. *A* is the magnet; *a b* a cylindrical collector of soft iron passing through the axis of the helix *c*, and connecting the poles of the magnet; accuracy of contact was found to be of considerable importance in the success of the experiment, and one side of the cylinder was carefully formed to a curve of about 2 inches radius for this purpose. Great advantage was found from a mechanical guide—not represented in the figure—to enable an assistant to bring up the connector rapidly and accurately to the magnet in the dark. The helix *c*, consisted of about 150 feet of

Fig. 369.



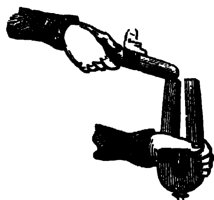
* The *first* spark was obtained by Professor Forbes on the 30th of March. It appears that the first document giving an account of the excitation of a spark from a permanent magnet, is by Signor Nobili and another dated from the Museum at Florence, 31st January, 1832.

copper wire, nearly $\frac{1}{70}$th of an inch in diameter, 7½ inches long, and containing 4 layers in thickness, which were carefully separated by insulating partitions of cloth and sealing-wax. The one termination *d e* of the wire passed into the bottom of a glass tube *h*, half filled with mercury, in which the wire terminated, and the purity of the mercurial surface was found to be of great consequence. The other extremity *f*, of the helical wire communicated by means of the cup of mercury *i*, with the iron wire *g*, the fine point of which may be brought by the hand into contact with the surface of the mercury in *h*, and separated from it at the instant when the contact of the connector *a b*, with the poles of the magnet is effected. The spark is produced in the tube *h*.

The success of the experiment obviously depended on the synchronism of the production of the momentary current by connecting the magnetic poles, and the interruption of the galvanic circuit at the surface of the mercury; with a little practice, Mr. Forbes was able to produce for many times in succession at least two sparks of a fine green colour from every three successive contacts.

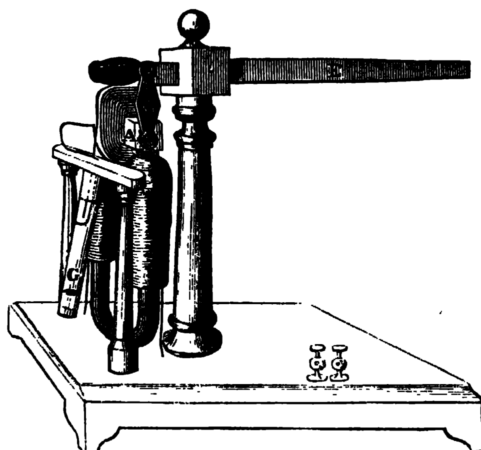
(997) The magnetic spark may be produced with great ease and certainty, and with a magnet of moderate strength by employing the little arrangement shown in Fig. 370. It consists merely of a cylinder of soft iron, round the centre of which is wound a few feet of small insulated copper wire; to one end of this wire is soldered a small disc of copper which is well amalgamated, the other end is bent up, the point cleaned and amalgamated, and brought into contact with the disc. On laying this cylinder across the poles of the magnet, and then suddenly breaking contact, the point and the disc become separated at the same time, and the spark appears. Another excellent method of showing the spark from a single pole, and which is well adapted for the lecture table, is to mount a strong bar magnet (about 2 feet long) horizontally on a stand, to wind 18 or 20 feet of wire, the ends of which are prepared, as in the last arrangement, round a piece of wood, through which a hole is cut large enough to allow the end of the magnetic bar to work freely; rapid horizontal motion is then given to the coil by means of a multiplying wheel, and contact between the point and disc is broken by the end of the bar striking a small piece of wood loosely placed at one end of the aperture in the wood, through which one end of the copper coil passes. A series of sparks which, if the magnet is powerful, are very brilliant, appear with such rapidity as to keep up a constant light.

Fig. 370.



(998) In the fourth volume of the *London and Edinburgh Philosophical Magazine*, page 104, a very simple method of detonating a mixture of oxygen and hydrogen gases by the magneto-electric spark was described by the late Dr. Ritchie. It forms an excellent class experiment. Round the soft iron lifter of a horse-shoe magnet capable of carrying fifteen or twenty pounds, 10 or 12 feet of insulated copper wire are wound. To the ends of the coil 2 thick copper wires are to be soldered in order to form a complete metallic circuit when the lifter is in contact with the poles of the magnet. The magnet is mounted, poles upwards, on a wooden stand, having a pillar with an arm or lever passing through a mortice in the top of it, for the purpose of removing, by a sudden jerk, the lifter from the poles of the magnet. In front of the magnet a glass tube is fixed, having its top closed by a cap of box-wood, through which the copper wires soldered to the extremities of the coil pass, as near air-tight as possible, into the glass tube; the end of one wire being flattened, is bent at right angles and well amalgamated. The other, which is straight, can be brought down or removed from it by means of the lever. The whole arrangement will be readily understood by a simple inspection of Fig. 371. The mixed gases are introduced into the tube *G* by means of a bent or flexible tube. On giving the lever *E* a smart blow with the palm of the hand, the iron lifter *A B* is suddenly removed from the poles of the magnet, a current of Electricity is induced in the coil, contact between the wires in the tube *G* is broken, a spark appears, and the gases are immediately exploded.

Fig. 371.



(999) *The Magneto-electrical Machine.*—The first magneto-electric machine—that is, an instrument by which a continuous and rapid succession of sparks could be obtained from a permanent magnet—was invented by M. Hipolyte Pixii, of Paris, and was first made public at the meeting of the *Académie des Sciences*, on Sept. 3rd, 1832. A description of this invention will be found in the *Annales des Chimie*, for July, 1832, and a representation of it in Becquerel's

"Traité de l'Electricité," vol. iii. With this machine, furnished with a coil about 3,000feet in length, sparks and strong shocks were obtained; a gold leaf electrometer was made to diverge, a Leyden jar was weakly charged, and water was decomposed.

(1000) At the meeting of the British Association at Cambridge, in June, 1833, Mr. Saxton exhibited his improvement on Pixii's machine, and in the August of the same year, a large instrument on the new construction was placed in the Gallery of Practical Science, in Adelaide Street. With this machine were exhibited the ignition and fusion of platinum wire, and the excitation of an electro-magnet of soft iron; and in December, 1835, there was added to the instrument the double armature, producing at pleasure either the most brilliant sparks and strongest heating power, or the most violent shocks, and effecting chemical decompositions. Saxton's machine differs principally from Pixii's in two respects: first, in M. Pixii's instrument the magnet itself revolves, and not the armature; and secondly, the interruptions, instead of being produced by the revolution of points, were made by bringing one of the ends of the wire over a cup of mercury, and depending on the jerks given to the instrument by its rotation, for making and breaking the contact with the mercury.*

(1001) In the *Philosophical Magazine* for October, 1836, Mr. E. M. Clarke describes his ingenious arrangement of the magneto-electrical machine, in which the battery of magnets is placed in a vertical, instead of a horizontal position, whereby vibration (known to be so injurious to magnets) is materially lessened. Two soft iron armatures are employed; one is covered with 40 yards of thick copper bell wire, and is used for *quantity* effects, such as igniting platinum wire, magnetizing iron, producing the spark, deflagrating metals, &c.; and the other, the iron of which is only half the weight of the former, has 1,500 yards of fine insulated copper wire on it, and is used for the exhibition of those effects usually ascribed to intensity, viz., giving the shock, and effecting chemical decompositions.

(1002) Saxton's machine as at present constructed is exhibited in Fig. 372. Figs. 373, 374, 375, 376, 377, 378, show the different arrangements and their application to illustrate various phenomena. The letters in Fig. 372, answer to the same in the other figures. *A* is a compound horse-shoe magnet, composed of 6 or more bars, and supported on the rests *b e*, which are screwed firmly on the board

* A description and engraving of the machine deposited by Mr. Saxton in the Adelaide Gallery, in August, 1833, will be found in *Lond. and Edinb. Phil. Mag.*, vol. ix. p. 360.

B D; into the rest *e*, is screwed the brass pillar *c*, carrying the large wheel *f*, having a groove in its circumference, and a handle by which it can readily be revolved on its axis; a spindle passes from one end of the magnet to the other between the poles, and projects beyond them about 3 inches, where it terminates in a screw at *h*, to which the armatures, to be described immediately, are attached; at the further extremity is a small pulley, over which a gut band passes, by means of which, and the multiplying wheel *f*, the armatures can be revolved with great velocity.

(1003) The armatures or *inductors*, as seen at *F*, are nothing more

Fig. 372.

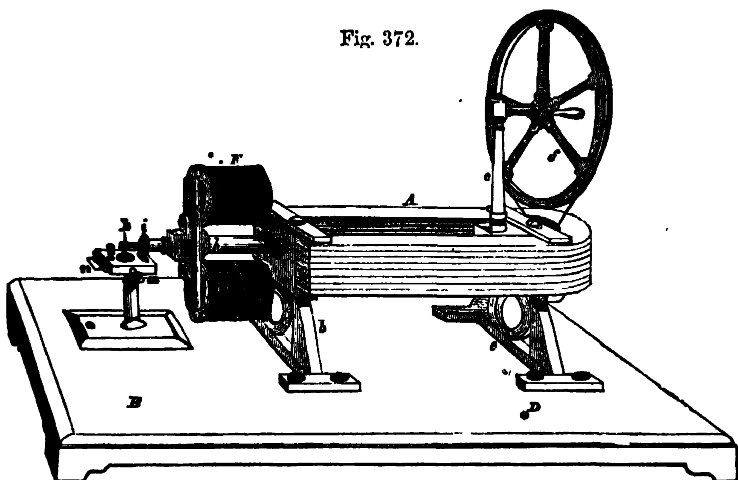


Fig. 373.

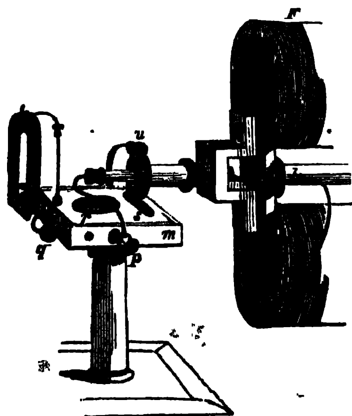


Fig. 374.

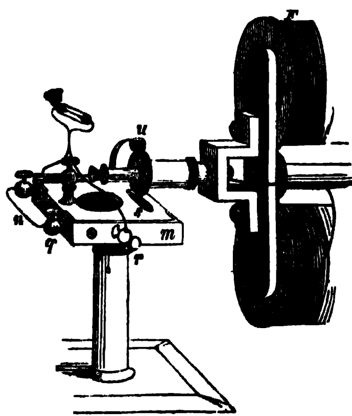


Fig. 375.

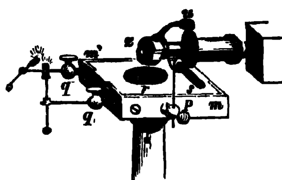


Fig. 376.

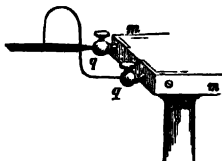


Fig. 377.

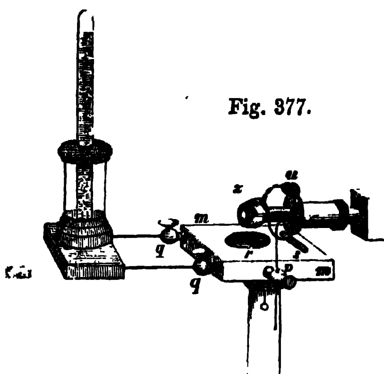
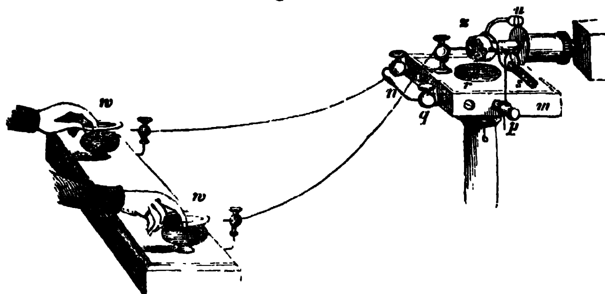


Fig. 378.



than electro-magnets; two pieces of round iron are attached to a cross piece, into the centre of which the spindle *h*, screws; round each of these bars is wound in a continuous circuit a quantity of insulated copper wire, one end being soldered to the round disc *i*, the other connected with the copper wire passing through, but insulated from it by an ivory ring. By means of the wheel and spindle, each pole of the armature is brought in rapid succession opposite each pole of the magnet, and that as near as possible without absolutely touching. The two armatures differ from one another. The one termed the *quantity* armature is constructed of stout iron, and covered with thick insulated wire. The other, the *intensity* armature, is constructed of slighter iron, and covered with from 1,000 to 2,000 yards, according to the size of the instrument, of fine insulated wire.

The *quantity* armature is adapted for exhibiting the magnetic spark, inducing Magnetism in soft iron, heating platinum wire, &c. The *intensity* is best adapted for administering the magnetic shock

(which from only a moderate-sized machine is so powerful, that few will venture to take it a second time), and for effecting chemical decompositions.

(1004) *The Flood Cup* is that part of the instrument to which the different arrangements and apparatus used to illustrate various phenomena, are attached. The one here represented can be used either with or without mercury; it consists of a square block of wood supported on a stand capable of being raised or lowered to the height required. Two hollows, *r* and *s*, are made on the top, into which mercury is put when that medium is required; the round metal disc *i* (Fig. 372), revolves in *s*, and the point *h*, just dips into *r*; the wire fork *n*, connects the two floods of mercury together. On revolving the armature, contact is continually broken and renewed at the point *k*, and a brilliant succession of sparks, forming almost a continuous light, is produced. Two pieces of stout brass *m*, bent at two right angles, are fixed to the sides of the wood block, but insulated from each other; to these are attached binding screws, which answer in every respect the same purpose as the mercury.

(1005) Fig. 373 exhibits a small electro-magnet connected with the apparatus. A small roller *u*, attached to a spring, presses on the circumference of the metal disc *i*, at the same time a bent piece of wire is fixed by the binding screw *p*, into the centre of the copper pin, the terminating wires of the electro-magnet being connected with the binding screws *q q*. Fig. 374 exhibits the arrangement for heating platinum wire, which is enclosed in a small glass tube. Fig. 375, the arrangement for igniting charcoal points, the break piece *z*, being screwed to the copper pin, and a wire spring inserted into the binding screw *p*; by this means contact is broken and renewed, as with the mercury and points shown in Fig. 372. Fig. 377 illustrates the method of decomposing water. Fig. 376, the combustion of steel by inserting a piece of wire in one of the binding screws *q q*, and a small file into the other; on turning the wheel of the machine, and drawing the wire over the surface of the file, brilliant scintillations are produced. Fig. 378, exhibits the arrangement for administering the magneto-electric shock. *w w* represent 2 glass cups containing a little acidulated water; into these the fingers or hands are to be dipped; a small metal bottom connects them with the binding screws, one of which is connected by a wire with the fork *n*; the other is inserted into the centre of the copper pin: on turning the wheel the magneto-electric shock is communicated.

(1006) The magneto-electric machine is certainly one of the most beautiful and instructive instruments of modern science; by it we see exemplified the close connexion between, if not the identity of,

the electric and magnetic forces; by it, the same heating, magnetizing, and decomposing powers, the same velocity of motion, the same physiological and the same chemical effects are shown to be common to both; and let us not forget that it is to the genius and labours of an *English* philosopher that we are indebted for the development of the leading principles on which this beautiful instrument is constructed. Let us remember that the unfolding of the laws of electro-dynamic and magneto-electric induction was effected by a countryman of our own, and that these brilliant discoveries were not (as many of the first importance are known to have been) the offspring of accidental or fortuitous circumstances, but purely the result of, and affording fine illustrations of that method of physical research introduced by the great reformer of philosophy (Lord Bacon), viz., *well-founded and well-verified inductions and deductions.*

(1007) The application of the magneto-electrical machine to the art of *electro-plating* was made and patented by Mr. J. P. Woolrich, of Birmingham.* In the 38th volume of the *Mechanics' Magazine*, page 146, will be found a full and illustrated account of the machine which he employed, and of the method of conducting the process. Mr. Woolrich made use of sulphite of potash as the solvent for the gold, silver, and copper, with which the articles were plated; and he gives in his specification a detailed account of the method of preparing the different "liquors." The thickness of the metallic coating to be deposited, depends on the time during which the article is submitted to the operation of the magnetic apparatus and solutions; a thin coating will be deposited in a few seconds, whilst to obtain a thick coating the article must be submitted to the constant operation of the magnet and solution for several hours. The distance at which the poles of the magnet should be placed from the ends of the armature will depend on the superficies of the article to be coated; the larger the superficies, the nearer must the magnet be placed to the armature; and the smaller the article, the greater must the distance be increased, the distance being inversely as the superficies of the article to be coated. If the surface of the article under the operation of coating becomes, while in connexion with the magnetic apparatus, of a brownish or darkish appearance, or if gas be evolved from its surface, the distance between the poles of the magnet and the ends of the armature must be increased until the metal contained in the solution is properly deposited. Mr. Woolrich subsequently introduced such improvements into the magneto-electric machine, that at the cost of about £15 he was able to construct an

* Patent dated August 1st, 1842; Specification enrolled, February 1st, 1843.

apparatus which was capable of depositing 60 ounces of silver per week.

The magneto-electric machine is now very extensively used in Birmingham as a substitute for the voltaic battery in the operation of electro-plating. A single Saxton's machine will, if kept in continuous revolution, precipitate from 90 to 100 ounces of silver per week from its solutions; and machines have been constructed by which 2½ ounces of silver per hour have been deposited upon articles properly prepared for this mode of plating (Miller's "Chemical Physics," p. 407).

(1008) A very few words will suffice to explain the theory of the magneto-electrical machine, as at present understood. As often as the bent ends of the armatures or inductors *F*, *F*, *F*, Figs. 372, 373, 374, are brought by the rotation of the wheel opposite the poles of the magnet, they become by induction magnetic; but they cease to be so when they are in the position shown in Fig. 372, viz., at right angles to it. Now, we have seen (991) that at the moment of the *induction* as well as of the *destruction* of the Magnetism in an iron bar surrounded by copper wire, currents of Electricity moving, however, in opposite directions, are induced in the wire, if the circuit be complete; the points *k*, Fig. 372, are therefore so arranged that they shall leave the mercury, and thus break the circuit in the wire surrounding the armature F, at the moment that its ends become opposed to the poles of the magnet; for which purpose they must be placed nearly at right angles to it: the circuit is thus broken at the precise moment that a rush or wave of Electricity is determined in the wire, and hence the electrical effects that are obtained. As, however, the currents alternate in opposite directions, we cannot obtain the oxygen and hydrogen gases from decomposed water *separately*, when the full power of the machine is employed; but by causing the wire *p*, Fig. 377, to rub on the break-piece *z*, instead of on the cylindrical part, one-half of the power of the machine is destroyed, but as the induced electrical current will be in one uniform direction, the usual results of polar decomposition may be obtained.

Various methods have been contrived for obtaining a continuous electric current in one uniform direction from the magneto-electric machines: several magnetic batteries are connected together, and the respective armatures are so arranged that each shall in turn become magnetic just before the preceding armature has lost its Magnetism, a current is thus caused to commence in one coil before it has ceased in that one which immediately precedes it.

(1009) The laws which regulate the magneto-electric force excited by Magnetism in the induction spirals, have been investigated by

Lenz, and his results agree with those which, in conjunction with Jacobi, he had previously found to regulate the intensity of the electro-dynamic force excited by voltaic currents.

These laws are ("Peschel's Elements of Physics," Vol. ii., p. 236):

1° That the magneto-electric energy excited in an induction spiral by means of Magnetism is equal to the sum of the electro-motive forces of all the individual coils of the wire; this is in accordance with the fundamental law of Ohm (394).

2° With equally powerful currents the magneto-electric force will be nearly proportional to the number of coils, the thickness of the wire exerting no influence on it; its intensity will, however, be slightly diminished by increasing the width of the coils.

The excitation of the current does not keep pace with the velocity of the rotation, the production and disappearance of the Magnetism in the iron cores requiring a certain time.

(1010) *Secondary Currents.*—If a small pair of voltaic plates be moderately excited, and a small short wire used to connect its mercury cups, no spark, or only a very minute one, will be perceived, either on making or breaking contact. As, however, the length of the connecting wire increases, the spark becomes proportionally brighter, "*until, from extreme length, the resistance offered by the metal as a conductor, begins to interfere with the principal result.*"*—(Faraday's "Ex. Researches," 1067.) If two equal lengths of wire be taken, and one made up into a helix, and the other laid out on the floor, and each used to connect the mercury cups of a small battery, very great difference will be observed in the size of the spark afforded by each on breaking contact. Supposing the length of each to be 60 feet, the wire laid on the floor will give a small bright spark, while the wire wound into a helix, will produce a large brilliant spark accompanied by a snap. Again, to render the fact still more decisive, take 100 feet of covered wire and bend it in the middle, so as to form a double termination, which can be communicated with the electrometer; wind one-half into a helix, and let the other remain in its extended condition; use these alternately as the connecting wire, and the helix will be found to give by far the strongest spark.

(1011) The spark and snap are much increased when a bar of soft iron, or what is better, a bundle of iron wires, are introduced into the axis of the helix; but it is only on breaking contact with the battery that the effect is produced; the reason is, that the iron, magnetized by the power of the continuing current, loses its Magnetism at the moment the current ceases to pass, and in so doing tends to produce an electric current in the wire round it.

(1012) These effects are evidently dependent on some affections of

the current in the conducting wire, and the spark produced when the cups of the electrometer are connected by a *short* wire, is the only one that can be considered as produced by the direct power of the battery; that the increase of the spark when the wire is lengthened does not depend on any thing analogous to *momentum* in the Electricity circulating through it, and consequently producing effects at the instant the current is stopped, is proved by the fact that the same length of wire produces the effects in very different degrees, according as it is simply extended or made into a helix, or forms the circuit of an electro-magnet. How then is it to be accounted for? The ingenuity of Faraday has provided an answer.

In his ninth series of "Experimental Researches," he has shown, that if a current be established in a wire, and another wire forming a complete circuit be placed parallel to the first, at the moment the current in the first is stopped, it induces a current in the same direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire induces a current in itself in the same direction, producing a strong spark.

The strong spark in the single long wire, or helix, at the moment of disjunction, is therefore the equivalent of the current which would be produced in a neighbouring wire, if such second current were permitted. Viewing the phenomena, therefore, as the results of the induction of electrical currents, the different effects of short wires, long wires, helices, and electro-magnets, may be comprehended. If the inductive action of a wire a foot long, upon a collateral wire also a foot in length, be observed, it will be found very small; but if the same current be sent through a wire 50 feet long, it will induce in a neighbouring wire of 50 feet a far more powerful current at the moment of making or breaking contact, each successive foot of wire adding to the sum of action; and by a parity of reasoning a similar effect should take place when the conducting wire is also that in which the induced current is formed; hence the reason why a long wire gives a brighter spark on breaking contact than a short one, although it carries much less Electricity.

(1013) If the long wire be made into a helix, it will then be still more effective in producing sparks and shocks on breaking contact; for by the mutual inductive action of the convolutions, each aids its neighbour, and will be aided in turn, and the sum of effect will be greatly increased.

(1014) The following experiments were made by the author shortly after the publication of Faraday's researches. Two sheets of thin copper, each 4½ feet long, and 26 inches wide, were cut into ribbons

1 inch wide; all the lengths were soldered together, and formed into a single coil, with list intervening. A continuous coil of copper ribbon, 234 feet long, was thus provided. At the commencement of the coil, and at intervals of 25 feet through its whole length, wires were soldered, which projected about 2 inches, and supported small cups to contain mercury. By this arrangement, the current could be sent through any length of ribbon, from 234 to 25 feet, and by the aid of the mercury cups, the effect produced on one part of the wire by the action of an electrical current sent through any other part could be examined. In describing some of the experiments made with this coil, which seem to bear on the present subject, we shall distinguish the cups by figures, indicating their position on the coil, thus:—

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
corresponding to	25.	50.	75.	100.	125.	150.	175.	200.	234.	feet.	

Exp. 1. When communication was made with the positive end of a pair of plates, contained in a pint cup, and excited by dilute sulphuric acid, and cup 1, and the wire from the negative end, dipped in succession into 2, 3, &c., to the end of the arrangement, the spark and snap increased in intensity to 4; at 5, it appeared the same, and afterwards went on decreasing to 10, where the spark was not nearly so large, nor was the snap nearly so loud; the maximum effect, therefore, seems to be produced with the battery when the current has traversed between 75 and 100 feet.

Exp. 2. When a half-pint battery was employed, no difference in the size of the spark could be perceived in 4, 5, 6, 7, 8; but it was larger and brighter in these cups than in 2, 3, and 9 and 10, in which it seemed about the same: with a pair of plates, containing about one-fourth the surface of metal, no difference in the size or appearance of the spark, could be perceived throughout the whole arrangement, after cup 2, being as bright at 10, as at 3.

Exp. 3. When a pair of plates, each 2 inches square, was employed, the spark seemed brighter at 9 and 10 than either 4, 5, or 6; with a pair 1 inch square, the difference was more marked; with a pair ½ an inch square, it was feeble in 2, 3, 4, after which it went on increasing, and at 10 it was much larger; with a pair a ¼ of an inch, a slight snap was several times heard accompanying the spark in the last 3 cups; but the sparks produced in the first 6 cups were decidedly smaller, and less bright.

Exp. 4. A pair ⅛ of an inch square was then tried: sparks were produced in all the cups; feeble in 2, and 3, but in 7, 8, 9, 10, bright; largest and brightest in 10.

Exp. 5. Strips of copper and zinc, ½ an-inch long, and 1/10th of an

inch wide, were immersed in the acidulated liquor, and connected with the coil; sparks were obtained in all the cups, bright in 8, 9, 10; the strips were then cut in half, and by rapidly breaking contact, sparks were obtained in 5, 6, 7, 8, 9, 10; they could only occasionally be got from 4, and not at all from 2 and 3. The strips were then reduced to about $\frac{1}{8}$th of an inch long, and $\frac{1}{20}$th wide; in 9, and 10, several sparks were obtained, but none could be got from any of the other cups.

Exp. 6. A large calorimotor, highly excited with nitrous acid, was then tried; the brightest and loudest spark was at 2; the snap was very loud, and could be distinctly heard in a room, at the bottom of a flight of stairs, the door being shut, and also the door of the room in which the experiments were made; it was as loud, every time contact was broken, as the explosion from a pint Leyden phial; the sparks were very vivid, and evolved copious fumes of mercury; these effects rapidly diminished as the connecting wire approached the termination of the coil, and at 8, 9, 10, the sparks were not more brilliant nor louder than those produced by the half-pint battery.

Exp. 7. The shock with this apparatus did not increase with the spark: when a brass conductor was grasped by the hand, and kept permanently in 1, and another held in the left hand, and dipped successively into each of the other cups, in which contact with the battery was rapidly broken by an assistant, the large calorimotor being employed, the following were the results:—

Exp. 8. The left hand conductor being in cup 2, and contact with the battery broken in it, the shock was very slight; in 3 it was stronger, and went on increasing to 10, where it was strong enough to be felt at the elbows; now the spark and snap were most intense in 2, and least in 10; hence the shock appears to be inversely as the spark.

Exp. 9. The left hand conductor was then dipped into the cup *next* to that in which contact was broken, being out of the circuit of the current, as for instance in 3, while contact was broken in 2; the shock went on increasing, as before, to the end of the arrangement; it was then kept permanently in 6, while contact was broken in all the other cups; in 2, 3, 4, the shocks were distinctly felt, and went on increasing to 9.

Exp. 10. The current was then passed from 2 to 9, while the conductors were held in 1 and 10, then from 3 to 8, then from 4 to 7, then from 5 to 6, shocks were felt in all cases; strongest when the current was from 2 to 9, and weakest when from 5 to 6.

Exp. 11. The wires from the battery were then connected with 1

and 2, and the conductors held in 3 and 4, then in 1 and 3, while the conductors were in 4 and 5, 1 and 4, 5 and 6, &c.; but no shocks were felt, even when the wires from the battery were in 1 and 8, and the conductors held in 9 and 10.

Exp. 12. Although, however, no shock could be obtained *directly* from this arrrangement, yet the existence of a secondary current was easily proved by the galvanometer, when the positive wire from the battery was in 1 and contact broken by the negative wire in 2, one wire of the galvanometer being in 3, and the other in 10, the needle was strongly deflected in a direction indicating the passage of a current in the same direction as the inducing current, that is, from 3 to 10. When the needle had taken up its position, it was retained in it by a pin; contact was then broken in 2, and the needle was immediately deflected in a contrary direction, showing now the passage of a current from 10 to 3.

Exp. 13. By employing a coil apparatus powerful shocks were obtained from the secondary current; the wires from the large calorimotor being in 1 and 2, and the terminal wires of the primary coil in 3 and 10, shocks felt at the elbows occurred every time contact was broken, and when this was done rapidly by a revolving wheel, or by Ritchie's rotating magnet, the succession of shocks was almost intolerable; when one of the wires of the primary coil was dipped in the same cup in which contact with the battery was broken, the shocks were very violent, even with a half-pint battery. When a wheel was employed to break contact. the scintillations were very brilliant, when it was connected with the first four cups of the coil. The well known optical illusion, of a body in rapid motion appearing stationary, was beautifully shown when the room was darkened, and the large battery used. Without the intervention of the coil, the shocks obtained on breaking contact, by means of a wheel, were not so strong as was expected. The most efficient method in this case was to draw the end of the connecting wire rapidly over the edges of the ribbon, from the centre to the circumference.

Exp. 14. Secondary shocks were obtained from the coil *immediately; i. e.*, without the intervention of the coil, by dipping the conductors grasped by the hand, in 10, and the negative cup of the battery, while contact was broken, in 2, 3, 4, 5, 6, 7, 8, and 9; in the last three, the shocks were as strong as could be given with any other arrangement of the apparatus, and when the coil was interposed, very severe, even when contact was broken by 2, and a half-pint battery employed.

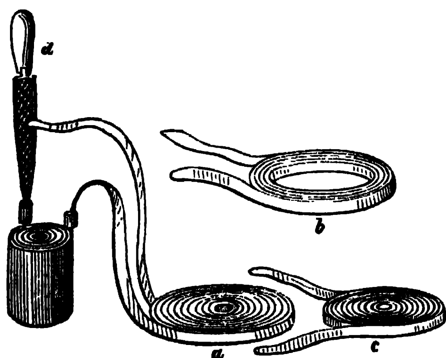
Exp. 15. The wire from the zinc end of the battery was then kept permanently in 10, and contact with the copper end broken in 9, 8, 7,

6, 5, 4, 3, and 2, the left-hand conductor being in 1, and the right in the positive cup. Shocks were felt in all; slight in 9 and 8, and strong in 4, 3, 2.*

These results agree very closely with those obtained by Professor Henry, of New Jersey, Princeton, to whom we are indebted for a very elaborate investigation of the phenomena of the induction of galvanic currents, and for the discovery of analogous results in the discharge of ordinary Electricity.

(1015) It was found by this experimentalist that when the length of the coil is increased, the battery continuing the same, the deflagrating power decreases, while the intensity of the shock continually increases, but that there is a limit to the increase of the intensity of the shock; and this takes place when the increased resistance or diminished conduction of the lengthened coil begins to counteract the influence of the increasing length of the current. When the intensity of the battery is increased, the action of the short ribbon coil decreases, but it is surprisingly increased when the length of the coil is increased in proportion. Thus Dr. Henry found that the current from a battery of 10 pairs of Cruickshank's trough, which, when sent through the ribbon, *a*, *b*, or *c*, (Fig. 379) produced scarcely any effect; when passed through a spool of copper wire $\frac{1}{16}$ of an inch in diameter, and *five miles* long, gave shocks too strong to be taken through the body; and that a battery composed of 6 pieces of copper bell-wire $1\frac{1}{2}$ inch long, and an equal number of pieces of zinc of the same size, was capable, through the medium of this long spool, to give shocks at once to *twenty-six persons* joining hands; though when a simple battery, exposing a zinc surface of $1\frac{3}{4}$ square foot was employed, no shock, or at most a very feeble one only, could be obtained.

Fig. 379.



(1016) Fig. 379 represents the method by which battery contact was broken and renewed in Professor Henry's experiments: *a* is the ribbon coil about 100 feet long; *d*, a rasp, the end of which communicates with the zinc cylinder of the battery through the medium of a cup of mercury; one end of the ribbon is placed perma-

After these experiments were made, the ribbon was cut down the midde, and

nently in the cup connected with the copper element, and by drawing the other end smartly over the surface of the rasp, a series of brilliant sparks are produced, and the electrical current through the coil is rapidly broken and renewed.

Now on placing coil *c*, containing about 60 feet of insulated copper ribbon on coil *a*, a plate of glass being interposed, and sending the electrical current from the battery through *a*, it was found that as often as the circuit was interrupted, a powerful secondary current was induced in *c*, and that when the ends of this coil were rubbed together, sparks were produced; when a small coil of wire enclosing a needle was interposed, the needle became magnetic; when a small horse-shoe of soft iron, surrounded by a coil of wire, was interposed, Magnetism was developed; when the ends of the coil were attached to a small decomposing apparatus, gas was given off at each pole; and when the body was interposed, a shock, though a feeble one, was experienced.

When, instead of a ribbon coil, a helix containing 2,650 yards of fine insulated wire was placed on coil *a*, the magnetizing effects disappeared, the sparks were smaller, and the decomposition less; but the shock even from a single rupture of the battery current was sufficiently powerful to be sent through 56 persons, and was too strong to be received with impunity by a single individual. When a helix containing 1,500 yards of wire $\frac{1}{125}$ of an inch in diameter was placed on coil *a*, scarcely any effects could be obtained; nevertheless when the ribbon coil was made into a ring, as shown in *b*, (Fig. 379) and the long spool of wire placed in the centre, shocks sufficiently intense to be felt at the shoulder, when passed only through the forefinger and thumb, were obtained, sparks and decomposition were produced, and needles were rendered magnetic.

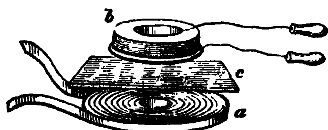
(1017) By these experiments it is proved that the induced current is diminished by increasing the *length* of the wire, and that the more so in proportion as the *size* of the wire is diminished; it is also shown that when a ribbon coil is employed, the induced or secondary current has the properties of one of considerable *quantity*, but of moderate *intensity:* and that when a helix of small copper wire is used, the

soldered together so as to form a length of about 460 feet, $\frac{1}{8}$ an inch wide, which was insulated and wound as before, into a spiral: the maximum spark, with this arrangement, a pint battery being used, was at about 150 feet; and with a very small voltaic pair, the largest and brightest spark was still at the extremity of the spiral; on the whole, the effect of dividing the copper ribbon was to diminish the *size* of the spark, but greatly to increase the intensity of the shock, which, when obtained from the last cup, and the negative end of the battery, was very severe. Water was readily decomposed by the secondary current, developed by this arrangement.

secondary current is one of small *quantity*, but of great *intensity;* the difference between the currents induced in the two cases is precisely similar to the difference which we notice between the Electricity from a voltaic battery consisting of a single pair of plates, and that from a voltaic arrangement consisting of a number of pairs in series weakly charged, as from the water battery (339). The fact that the induced current is diminished by a further increase of the wire after a certain length has been attained, is, as Dr. Henry observes, important in the construction of the magneto-electrical machine, since the same effect is produced in the induction of Magnetism. The wire on the inductor of the machine may therefore be of such a length, relative to its diameter, as to produce shocks but no decomposition; and if the length of the coil be still further increased, the power of giving shocks may also become neutralized, from the increased resistance offered to the induced current by the great length of wire: a good idea of the difference between *quantity* and *intensity* may be formed by supposing that in the first there is a large current moving slowly without any or but small resistance, and in the second a small current moving with great velocity, but still having a resistance to overcome.

The experiments of Professor Henry, relative to the induction of secondary currents at a distance, are exceedingly striking. By sending an intermitting current of Electricity through the spiral *a*, (Fig. 380), and placing the helix of thin wire *b*, over it, a plate of glass being interposed, shocks may be obtained on grasping the handles attached to the coil. When *a*, consisted of about 300 feet of copper ribbon, 1½ inch in width, and *b*, a helix of copper wire 5 miles long: Dr. Henry found that shocks might be obtained when the coils were *four feet apart;* and at a distance of 12 inches they were too strong to be taken through the body: the Professor also mentions a very instructive method of exhibiting these astonishing experiments, which we have frequently adopted in the lecture-room, viz., to cause the induction to take place through the partition walls of two rooms, for which purpose a coil, about 100 feet of ribbon, is suspended against the wall in one room, while a person in the adjoining room receives the shock by grasping the handles of a helix of about 300 yards of thin wire, and approaching it to the spot opposite to which the coil is suspended. The effect is as if by magic, without a visible cause. It is best produced through a door or thin wooden partition.

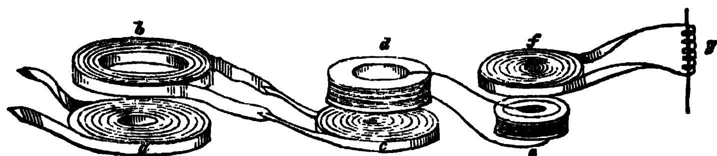
Fig. 380.



(1018) When an intermitting electrical current is sent through the

ribbon coil *a*, (Fig. 381), a secondary current is, as we have seen, induced

Fig. 381.



in *b*, placed at a distance above it. Dr. Henry further ascertained that this induced secondary current, by passing through the coil *c*, was capable of inducing a current of the *third order* in the helix *d;* and that this coil again, by passing through the helix *e*, induced a current of the *fourth order* in the coil *f*, as was proved by the power possessed by this coil of magnetizing the needle *g;* he further determined that there existed an *alternation* in the direction of the currents of the several orders, commencing with the secondary,—it was as follows:

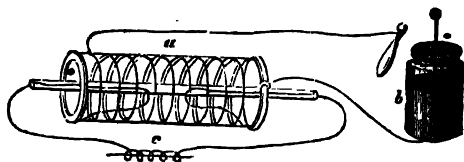
Primary current	+
Secondary current	+
Current of the third order	—
Current of the fourth order	+
Current of the fifth order	—

From our previous knowledge of this subject, the induction of currents of different orders, of sufficient intensity to give shocks, &c., could scarcely have been anticipated. The secondary current consists, as it were, of a single wave of the natural Electricity of the wire, disturbed but for an instant by the induction of the primary: yet this has the power of inducing another current, but little inferior in energy to itself; and thus produces effects apparently much greater, in proportion to the quantity of Electricity in motion, than the primary current.

(1019) In Fig. 381, the current induced in *f* by the helix *e*, is one of *quantity;* the effects, however, of the induced tertiary current in *d* would be those of *intensity;* and by grasping metallic handles, attached to the ends of that helix, shocks may be received; thus a quantity current can be induced from one of intensity, and the converse. Dr. Henry found that on interposing a screen of any conducting substance, between *a* and *b*, no secondary currents could be obtained; a circular plate of lead, for instance, caused the induction in *b* almost entirely to disappear; but when a slip of the metal was cut out in the direction of a radius of the circle, the induction was not in the least interfered with: again, the coil *b* being placed upon *a* with the two ends separated, and on the coil the helix *d*, shocks could be obtained from the latter as if the coil were not present; but when

the ends of *b* were joined, so as to form a perfect metallic circuit, no shocks could be obtained. The explanation of this apparent mystery was at first obscure; it was, however, subsequently referred by Dr. Henry to the changes in the direction of the induced currents: the secondary current, which is induced in the screening plate, or closed ribbon coil, is in the same direction as the current from the battery; it nevertheless tends to induce a current in the adjacent conducting matter of a contrary direction. A similar reaction, as it were, may be observed by placing on a flat ribbon coil, containing about 100 feet of metal, another similar coil, and then taking the shock from the first when the ends of the second are joined, the intensity will be found to be very materially diminished; although, if the ends of the second coil be not joined, no difference in the intensity of the shocks will be perceived.

Fig. 382.



(1020) By employing the arrangement shown in Fig. 382, Professor Henry succeeded in demonstrating that the discharge from the Leyden jar possesses the property of inducing a secondary current precisely the same as the galvanic apparatus. A hollow glass cylinder *a*, of about 6 inches in diameter, was prepared with a narrow ribbon of tinfoil, about 30 feet long, pasted spirally around the outside, and a similar ribbon of the same length pasted on the inside; so that the corresponding spires of each were directly opposite each other. The ends of the inner spiral passed out of the cylinder through a glass tube, to prevent all direct communication between the two. When the ends of the inner ribbon were joined by the magnetizing spiral *c*, containing a needle, and a discharge from a half-gallon jar sent through the outer ribbon, the needle was strongly magnetized in such a manner as to indicate an induced current through the inner ribbon, in the same direction as that of the current of the jar. When a second cylinder, similarly prepared, was added, a *tertiary* current was induced in the inner ribbon of the second; and by the addition of a third cylinder, a current of the *fourth* order was developed.

(1021) In all the experiments that were tried, the results with ordinary and galvanic Electricity proved to be similar. A most interesting fact, however, came out in the course of the investigation: when the Leyden experiments were made with the glass cylinders, the currents, instead of *alternating*, as was the case in the galvanic experiments, were all in the same direction as the discharge from the

jar; but when the arrangement of coils and helices, Fig. 358, was used, the coils being furnished with a double coating of silk, and the contiguous conductors separated by a large plate of glass, the discrepancy vanished, and the alternations were found the same as in the case of Galvanism: thus the cylinders gave currents all in one direction, the coils in alternate directions. Dr. Henry made a great number of experiments, in order to get some explanation of these apparently anomalous results; and he at last succeeded satisfactorily in tracing them to the distances *of the conductors*. Thus two narrow strips of tinfoil, about 12 feet long, were stretched parallel to each other, and separated by thin plates of mica to the distance of about $\frac{1}{30}$th of an inch. When a discharge from the half-gallon jar was passed through one of these, an induced current in the same direction was obtained from the other. The ribbons were then separated by plates of glass to the distance of $\frac{1}{20}$th of an inch—the current was still in the same direction, or *plus*. When the distance was increased to about $\frac{1}{8}$th of an inch, no induced current could be obtained; and when they were still further separated, the current again appeared, *but was now found to have a different direction, or to be minus*; no other change was observed in the direction of the current, and the intensity of the induction decreased as the ribbons were separated. Thus, when the conductors are gradually separated, there is, it appears, a distance at which the current begins to change its direction, and this distance depends on the amount of the discharge, and on the length and thickness of the conductors. With a battery of 8 half-gallon jars, and parallel wires of about 10 feet long, Dr. Henry found that the change in the direction did not take place at a less distance than from 12 to 15 inches; and with a still larger battery and longer conductors, no change was found, although the induction was produced at a distance of several feet.

(1022) This subject has been more recently examined by Reiss. (*Pogg. Ann.* lxxxi., p. 428, and lxxxiii., p. 309; translated, *Phil. Mag.* 4th series, vol. iii., p. 173.) To infer the strength of the current, this excellent Electrician resorted to the ignition of a fine platinum wire, introduced into the circuit and passing through an air thermometer (168) of peculiar construction.

The following were the results of his investigation:—

1st. Two portions of the connecting wire of a battery which run closely parallel, act upon each other; the current will be weakened by this action when its two parallel portions move in the same direction, and strengthened when they move in opposite directions.

2nd. Two portions of a secondary current which run closely parallel, act upon each other; when the direction of the current through both

portions are identical, a weakening is the consequence; and when the directions in both portions are opposed to each other, a strengthening of the current is the result.

3rd. Currents of the *third*, *fifth*, and other *odd* orders, have the same direction as the original current; and those of the *second*, *fourth*, and other *even* orders, have among themselves one and the same direction.

When primary and secondary flat spirals, each containing about 50 feet of copper wire, are placed opposite to each other a peculiar reaction of the secondary upon the primary is observed. If the ends of the secondary be connected by a thick wire, the effect upon the primary current is the same as when the ends of the secondary remain wholly unconnected. If the ends of the secondary be joined by a long thin platinum wire, the reaction of the secondary is such as to enfeeble the primary. This enfeeblement increases up to a certain limit as the resistance is increased, from which forwards it diminishes until it becomes insensible.

Fig. 383.

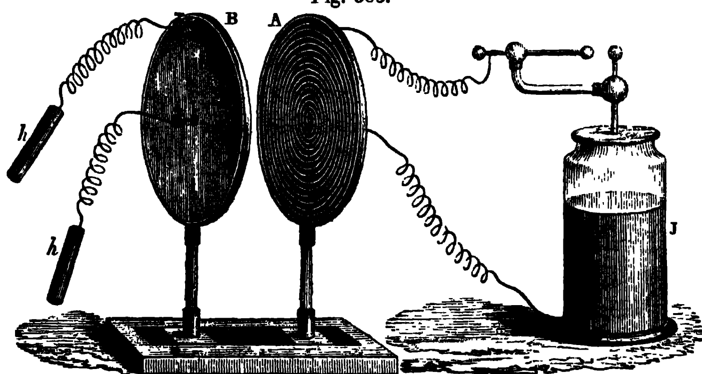


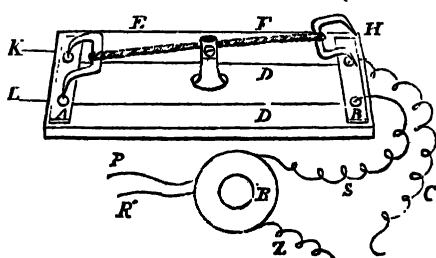
Fig. 383 shows Matteucci's arrangement of the apparatus for the development of secondary, or induction currents produced by the discharge of a Leyden jar or battery. A and B are discs of glass or gutta percha fixed vertically in metallic frames, and supported on insulating stands. They are about a foot in diameter. On one face of each is wound spirally, commencing from the centre, a long and well insulated copper wire, about $\frac{1}{10}$th of an inch in diameter, the ends of the wire pass through the discs at the centre, and near to the circumference, and are there terminated by binding screws. A is brought into the circuit of the jar or battery through a Lane's discharger (159), and the wired face of B brought close to it; every time the jar discharges, a shock of greater or less intensity, according to the interval between the discs, is experienced by a person

grasping the handles, *h h*. The spirals should be laid symmetrically on the discs, and the wire, after being well covered with silk, should be thickly coated with gum lac.

(1024) The reader, after the perusal of these beautiful experiments, will have no difficulty in understanding the rationale of the electro-magnetic coil machine. It was Mr. Callan, of Maynooth College, who first contrived a convenient apparatus for the illustration of secondary currents. A coil of thick insulated copper bell-wire is wound on a small bobbin; and on a larger rod with a hollow axis, in which the bobbin may be introduced at pleasure, a length of about 1,500 feet of thin wire is wound; the two coils are thus perfectly distinct from each other, and by sending the current from the battery through the interior coil, the Electricity present in the exterior coil is set in motion by its inductive influence; and from it both physiological and electrolytical effects may be obtained. The spark obtained on breaking battery-contact with the primary wire is generally fine and bright, in consequence of the *reflex wave* of Electricity which is generated in it; but if the ends of the exterior coil be brought into metallic contact, then little or no spark is seen when the primary circuit is broken, in consequence of the reaction of the induced current. If 100 yards of fine insulated copper wire be wound on a reel, and contact with an electrometer rapidly broken, shocks may be obtained by grasping metallic cylinders in connexion with the ends of the coil, from the reflex wave of Electricity which is generated; and if a bundle of iron wires be placed in the axis of the helix, the brilliancy of the sparks and the intensity of the shocks will be much increased in consequence of the *second wave* of Electricity, which we have seen is produced at the moment of the demagnetization of the iron.

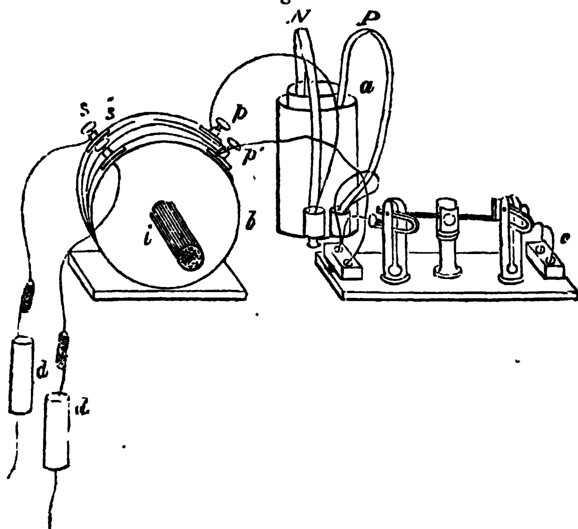
Fig. 384 represents a very convenient little apparatus devised by Dr. Golding Bird (*L. and E. Phil. Mag.*, vol. xii., p. 18), for rapidly breaking and renewing battery-contact with the primary coil. It is thus constructed:—a base board, about 8 inches in length, and 3 in breadth, is furnished at both ends with a piece of hard wood, *A* and *B*, each having 2 holes excavated for the purpose of holding mercury; each of these holes communicates by means of thick copper wires, *D D*, with that

Fig. 384.



opposed to it in the other piece of wood at the opposite end of the board. Midway, between the receptacles for mercury, is a wooden support, so contrived, that a piece of soft iron wire, $\frac{1}{8}$th of an inch in diameter, and 5 inches in length, may oscillate between the cheeks cut in its upper part, with as little friction as possible. Around this iron wire, *E F*, are wound two helices of thin insulated copper wire, in the same direction (from right to left), in such a manner that the two ends of one helix may terminate in the copper points *G H*, and the ends of the other helix in the points *K L*. Two small horse-shoe magnets (not shown in Fig. 384, but shown in their proper places, in Fig. 385) are then fixed on proper supports, so that

Fig. 385.



they may each be placed near an end of the iron bar, *E F*, in a vertical plane just posterior to it, so that on depressing the end F, of the bar, it may be opposite one pole (say the S.) of one magnet, and consequently the end *E*, will be opposite the other pole of the second magnet. On elevating the end *E*, the contrary will of course take place, and for this purpose, it is hardly necessary to say that the similar poles of the magnet should be in the same direction.

(1025) From this description it is evident that on connecting the cup of mercury in *A* or *B*, with the 2 plates of a single voltaic battery, the bar *E F* will become a temporary magnet, if the ends of either helix are allowed to dip in the mercury; and if connexion with the battery be properly made, the ends or poles of the temporary magnet will be repelled by the poles of the permanent magnet, to which they are opposed; the bar will consequently move, and so

cause the immersion of the ends of the second helix in the other cups of mercury; repulsion will again occur, and so on; about 300 oscillations of the iron bar can thus be obtained in a minute.

The coil is thus arranged: on a reel, with a hollow axis, 3 inches in length, are wound about 60 feet of copper wire, $\frac{1}{18}$th of an inch in diameter, covered with cotton thread for the purpose of insulation, the two ends being connected with *p p* (Fig. 385), so that by means of the binding screws communication may be made by wires with the contact-breaker and battery; this is the primary coil; over it a second insulated copper wire, $\frac{1}{80}$th of an inch in diameter, and about 1,500 feet in length, is wound, and the two ends are connected with *s s*, furnished with binding screws, for forming connexion with wires, for communicating the shock, &c.

(1026) The connexion with the battery is best made in the way shown in Fig. 384, in which *R* represents a section of the reel, *S* an end of the short helix connected with the mercury cup in *B*, *Z* the other end of the short helix connected with one plate of the battery, whilst the wire *C* connects the other cup of mercury in *H* with the other plate of the voltaic couple. When this is properly arranged, a series of induced currents may be obtained from *s s*, the extremities of the long helix, capable not only of communicating a series of intense shocks, but of exerting powerful electrolytic action; and when a bundle of soft iron wires is inserted in the hollow axis of the reel *i*, (Fig. 385), the dynamic power of the coil is considerably increased. In this case, indeed, the sparks produced when the ends of the helices round the iron bar *E F*, leave the mercury, are very brilliant, accompanied by a loud snapping noise and a vivid combustion of mercury, clouds of the oxide of that metal being copiously evolved.

(1027) If the ends *P R'*, of the long and thin coil are furnished with platinum points, and immersed in water acidulated with sulphuric acid, rapid electrolytic action ensues, torrents of minute bubbles of oxygen and hydrogen gases being evolved. If, instead of water, the points are pressed on paper moistened with iodide of potassium, electrolytic action ensues, iodine and oxide of potassium being separated. Solutions of neutral salts, such as sulphate of potash and soda, chloride of potassium, sodium, antimony, and copper, are also rapidly decomposed. In these experiments, as Dr. Bird remarks, it will be found that the great majority of the electro-positive elements (for example) appear constantly at one termination of the coil, *cæteris paribus*, but not all, for it must not be forgotten that on making, as well as breaking contact with the electromotor, an induced current takes place in the long coil, though of far weaker

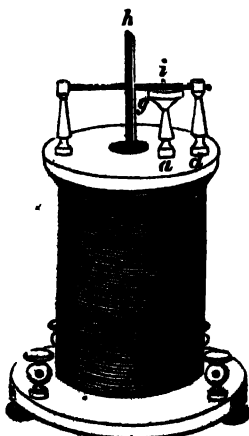
intensity than the latter, to which it is opposed in direction, and consequently in electrolytic effects.

(1028) If the brass conducting tubes *d d′* (Fig. 385), are grasped, even with the unmoistened hands, the intensity of the rapid succession of shocks will be found intolerable, even when the battery used consists but of two plates, presenting 4 or 5 square inches of surface; and with pairs of half an inch, the shocks obtained, when contact is rapidly broken (which in this case, is best done by a rotating magnet, motion being communicated by the fingers), are very disagreeable.

When the wires at the end of the conducting tubes, *d d′* are made to touch, small bright sparks are produced; and if, while the oscillating bar of the contact-breaker is vibrating rapidly, a large pair of plates being employed, a piece of well-burnt charcoal is fixed on one of the terminations, and the other drawn lightly over it, a rapid succession of brilliant sparks is obtained. These sparks depend entirely upon the induced currents, as the fine coil has no connexion with the battery. For the exhibition of this, as well as of the electric light of an energetic arrangement, pencils of that kind of artificial graphite found lining the interior of the iron cylinders used for the distillation of coal in gas manufactories are very far superior to box-wood, or indeed to any other form of charcoal.

By connecting the ends of the primary coil of this arrangement with the quantity inductor of the magneto-electrical machine, powerful shocks and strong electrolytic effects are obtained; the spring must rub on the double break, which in this experiment performs the same office as the contact-breaker; the coil, which, as we have seen, is, when revolving before the magnets a powerful source of Electricity, supplying the place of the voltaic couple.

Fig 386.

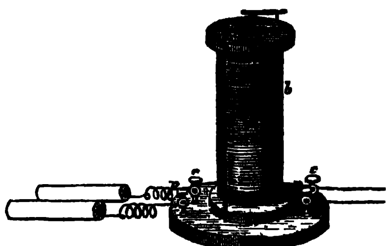


(1029) There are several other forms of the electro-magnetic coil machine, and many other modes of breaking battery-contact with the primary coil. Fig. 386 is a very elegant arrangement; the primary coil consists of about 35 feet of insulated copper wire (No. 12), and the secondary of 1,400 feet of silk-covered copper wire (No. 20), battery-contact is broken and renewed by the rotation of the soft iron bar *h*, which, mounted between two brass pillars, is situated immediately over the axis of the coil, in which is placed a bundle of iron wires; the electrical

current from the battery passes through the pillar *d*, and the axis carrying the iron bar; and contact is broken and renewed by the point *i* dipping, as *h* revolves, into, and out of, the mercury contained in the brass cup *g*, mounted on the brass pillar *a*, through which the circuit is completed; communication with the voltaic battery is made through one pair of the binding screws on the base of the instrument; and the shocks, electrolytical effects, &c., are obtained from wires attached to the other pair.

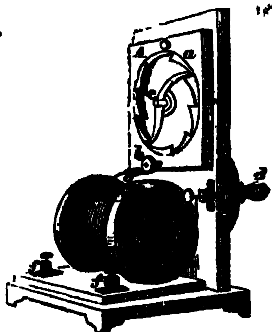
(1030) Fig. 387 represents another form of the instrument which possesses this advantage over the last, viz., that it does not require mercury. The current from the battery passes from the binding screw *p*, up the wire *a*, which terminates in a small disc of iron, arranged immediately over the bundle of iron wires in the axis of the coil, from which however it is prevented from coming immediately into contact, when the machine is not in action, by the horizontal spring by which it is connected with the wire *a*. The binding screw *c*, is connected with a wire, the top of which is seen in the figure rising above the coil. On the top of this wire is a horizontal strip of metal tipped with platinum, and with this, by the action of the spring, the disc of iron is kept in contact; now, when connexion is made with the battery through the wires *p* and *c*, the central core of iron wires becomes magnetized, and consequently attracts the disc of iron, thus breaking battery-contact; the current being shut off, the disc of iron is again raised by the spring, and thus contact is broken and renewed with amazing rapidity. The secondary effects are obtained from the handles attached to *p c*. For medical purposes, this is decidedly the best arrangement of the coil machine, as it is more compact than any other, and dispenses with the use of mercury.

Fig. 387.



(1031) In Fig. 388 is a representation of the Rev. F. Lockey's electro-magnetic coil machine, to which is attached an apparatus for producing luminous galvanic rings. The contact-breaker is the curved spring C, which is carried rapidly round by the multiplying wheel and handle *d*, striking in its course against the notches

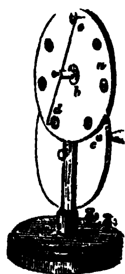
Fig. 388.



in the interior of the metallic circle *b*. This circle must have an odd number of teeth or notches, in order that the ends of the S-shaped spring may produce the spark at opposite parts of the ring; when there are 25 or 35 breaks, the resulting ring of sparks is exceedingly beautiful.

The diameter of the ring *a b* may be about 5 inches; rings a foot in diameter produce very brilliant effects; they may be made of different metals, and if corresponding springs be used, there will be a different light for each. The rings are secured in the circular rabbet of the square piece of wood, *A*, by small turn buttons; one end of the primary coil is in communication with the ring, the other is in connexion with the binding screw *e*, where one of the battery wires is to be fixed. The spring *c* has metallic communication with the other pole of the battery by means of its metallic socket, to which a wire is soldered and brought down to another connecting piece symmetrical with *e*, but not visible in the figure; a small portion of this wire is seen at *g*; *f f* are the usual connecting pieces for administering the shock.

Fig. 389.

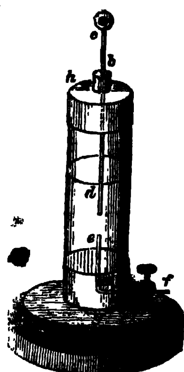


(1032) The *Scintillating circle*, Fig. 389, is another of Mr. Lockey's instruments. Seven or any other uneven number of fine files are procured, such as are used in certain engravers' work; they are of a flat and circular form, about $\frac{3}{8}$ths of an inch in diameter; they are arranged and fixed upon an immovable disc *a*; each is in metallic contact with the other, and the whole with the terminal wire of the battery, a powerful coil being interposed. In the centre of the disc is the brass axis *b*, carrying a small pulley, to which rapid rotation can be communicated by the multiplying wheel *c*. This pulley carries the steel wire *d*, *e*, pointed at its extremities, and bent at such angles as lightly to drag over the faces of the files in rotation. The wire is removable at pleasure to admit of its adjustment or replacement. The central axis has a wire leading to the other terminal of the battery. On putting the apparatus in action, contact is made and broken alternately at nearly opposite diameters of the disc. The effect to the eye is a continuous circle of radiant and splendid scintillations. This is perhaps one of the most delicately beautiful of electrical experiments. The effect is much improved if instead of separate pieces of steel inserted in the brass ring, the *whole circle* is formed of steel, either cleaned off with a fine file and left purposely unpolished, or, better still, formed into a continuous and fine file over its whole surface.

(1033) The *Water Regulator*, Fig. 390, also contrived by Mr.

Lockey, is a useful piece of apparatus for the purpose of modifying the physiological effects of the galvanic shock obtained by the medium of the self-acting *coil* or other source of power. The most powerful shock can by this regulator be readily reduced to one in the mildest form. In the medical administration of galvanic Electricity, this is a point of some importance, as obviating the necessity of any adjustment of the size of the battery, the depth to which its plates are immersed, &c.; *h* is a glass tube about 5 inches in length, capped at each extremity; this tube rests upon, but is not fastened to, the base *g*, as it may sometimes be desirable to attach the regulator *directly* to the connector of the coil, by the wire *f*. The fixed copper wire *e a f* bent to a right angle at *a*, passes out close to the bottom of the cap, and is fastened by the screw connector *f*. This part is not quite correctly represented in the figure. The base *g* should be so shaped that the whole of the connector be on a level with the bottom of the cap *a g*. The copper connecting wire *c b d* passes through a stuffing-box in the centre of the upper cap *h* (which unscrews in order to introduce any convenient quantity of water). The apparatus is interposed in the circuit between one of the extremities of the coil and the person about to receive the shock; and, according as the points of the wire *d* and *e* are approximated to, or separated from one another, will be the strength or the gentleness of the shock.

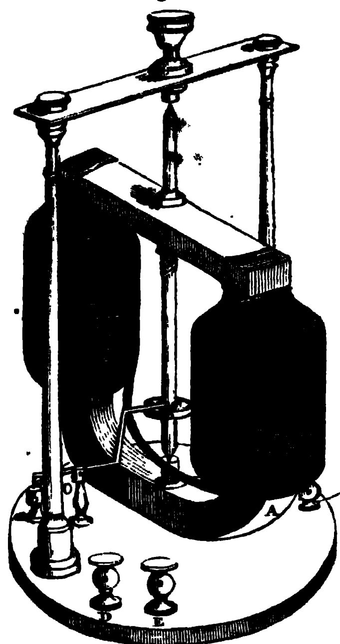
Fig. 390.



(1034) In Fig. 391, we have an engraving of a very powerful arrangement of the electro-magnetic coil machine, made, and presented to the author, by Mr. W. T. Henley. A, a series of U-shaped bars of soft iron, bolted down to a base board, and wound with 4 coils of No. 14 covered copper wire to within an inch from either extremity; over this are wound 1,000 yards of No. 34 covered wire in one continuous length. B, the revolving armature which rotates between the poles of the magnet fixed on an axis, the lower end resting on a hard steel cap, the upper kept in its position by a screw passing through a flat piece of metal mounted on 2 brass columns. O, the apparatus for breaking contact, consisting of a small lever *a*, suspended on a pillar, one end dipping into a mercury cup *b*, and the other end provided with a friction roller, running on an undulating wheel *c*, the prominent part of which, raising the end of the lever, dips the other end into the mercury, a spring *d*, raising it out when the roller falls on the lower parts of the wheel. A break-piece formed of ivory and brass may be

substituted for this, but the oxide of the metal formed by the spark is such an imperfect conductor, that 3 cells have no more effect than 1 with the mercury. D E are the binding screws for forming connexion with the battery; the opposite screws are the ends of the secondary coil. On the same side of the base with the last (not seen in the wood-cut), is an ivory knob, which being turned, connects the ends of the secondary coil, either to diminish the primary spark, as the armature will then rotate for hours without burning the mercury, or to prevent the operator from receiving an unpleasant shock while adjusting the instrument. The ends of the thick wire are passed through the base, those from one pole soldered to E, those from the other to the mercury cup; the pillar C, and binding screw D, are connected together. This machine works very well with 1 or 2 cells of Smee's battery; and with an intensity series of 8, the secondary current is exceedingly powerful, the spark passing $\frac{1}{8}$th of an inch through air; with a battery of 10 of Sturgeon's cast iron pots, the spark from the secondary coil passes $\frac{1}{4}$th of an inch through air, and brilliantly deflagrates gold and silver leaf; the shock would be far too powerful to be taken through the body, for when only two fingers are included in the circuit, it is sufficiently intense to be felt at the shoulders. With such a battery power the sparks from the primary coil are brilliant in the extreme; and from the ease with which the ends of the secondary coil are united and disunited, viz., by merely turning the ivory knob, the instrument is admirably adapted for demonstrating at the lecture table the induction and reaction of electrical currents; when the ends of the secondary, are disunited, the sparks from the primary are large and brilliant; when united, they are small and faint.*

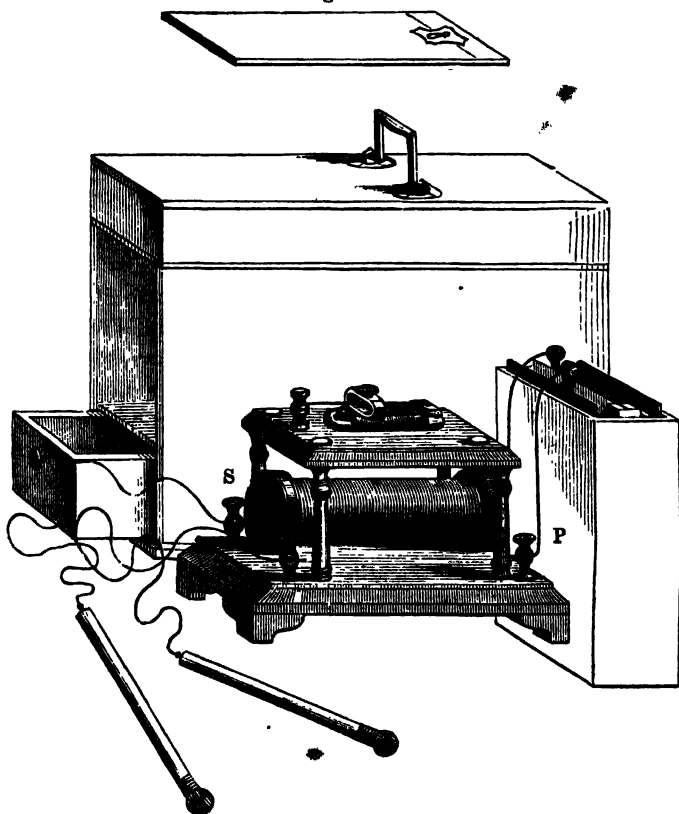
Fig. 391.



* Bachhoffner and Sturgeon appear to have first noticed that a bundle of iron wires insulated by a coating of varnish, and introduced into the axis of the primary coil, give a more powerful induced current than a massive bar of iron. Magnus and Dove (Peschel's Elements of Physics, vol. iii., p. 237) tried to ascertain the cause of this increased effect. They found that when the wires were enclosed

(1035) The electro-magnetic coil machine is from its convenience and portability admirably adapted for the medical administration of Electricity, and numerous are the forms which it has received for this purpose. Fig. 392 shows Messrs. Knight's arrangement, which they

Fig. 392.



thus describe: Round a hollow cylinder of wood a considerable length of stout copper wire, covered with cotton thread for the pur-

in a metal case, the force of the current was the same as if it had been sent through solid iron. But when the tube was slit, or when the wires were not enclosed at all, the efficiency of the current was greatly heightened. Dove found on prosecuting his inquiries still further, that two perfectly equal induction spirals provided with different bars or sets of wires, even if they deflected the needle of a galvanometer equally, gave shocks of unequal intensities; he therefore inferred that the increased physiological effects depend partly on the internal structure of the iron, partly on the discontinuity of the mass, and that the greater effect is owing to the more rapid suspension of the current caused by this discontinuity. The greater intensity of the shock caused by rapidly establishing and breaking the contact of the battery admits of a similar explanation.

pose of insulation, is wound. The two ends of this coil are metallically connected with the binding screws P P on the base board of the apparatus (one of these is not seen in the cut); over this coil a very considerable length of much finer copper wire, also insulated, is wound. The two ends of this second coil are metallically connected with the binding screws S S. The coil of thick wire is the *primary*: through it the current from the battery circulates, to which it is connected by means of two stout copper wires, one proceeding from the silver and the other from the zinc element, 2 ends of the wires being inserted respectively into the binding screws of the battery, and those representing the ends of the primary coil P P. The coil of thin wire, termed the *secondary*, is destined to communicate to the patient the Electricity which is developed in it by induction every time contact between the primary coil and battery is broken and renewed. The breaking and renewing of the battery contact is effected by a little electro-magnet with a vibrating armature, placed on the stage of the apparatus, through which, by a suitable contrivance, the current from the battery is caused to pass at very short intervals. The vibrating motion of the armature throws on and cuts off the electric current from the coil, and a rapid series of shocks may thus be communicated to a patient, being directed through any part of his body, by means of the sponge directors shown in the figure. The wires to which the sponges are attached pass through tubes of glass which, while they serve as handles for the operator, prevent at the same time the shocks from passing through his own body. The inductive effects of the coil, or, in other words, the power of the shock, is increased or diminished, by introducing into, or withdrawing the bundle of soft iron wires from, the axis of the wooden cylinder. The apparatus is packed in a convenient mahogany box, in which it is worked, but from which it is removed in the figure in order to show its construction.

(1036) Fig. 394 represents the author's arrangement of the *Medico-Electro-Dynamic Coil Machine*, which is constructed with the object of regulating to the greatest nicety, not only the strength, but also the frequency in the direction of the shocks. It consists of a coil of about 100 yards of covered copper wire wound on a hollow core of wood, in the axis of which a bundle of iron wires may be inserted, so as to combine the effects of *magneto-* with those of *volta*-electric induction. The coil is covered with black leather or velvet, and is fixed by screws to the base board of a platform, on the upper table of which stands a piece of clock-work apparatus, destined to give revolving motion to a brass disc, provided with platinum teeth or cogs, as seen in the figure. This clock-work is in metallic connexion

with one of the poles of the battery, which consists of two cells on Mr. Smee's plan; the other pole of the battery is metallically united through the coil with a small brass stage, to which is adapted a piece of steel spring tipped with platinum, and which is so arranged as to come into contact with each tooth or cog of the disc during its rotation; by means of a screw, the degree of force with which it presses on the cogs is readily adjusted.

The manner in which this machine acts will be clearly understood by reference to the general principles of *volta-inductric action*. When the battery circuit is completed through the coil, and contact established between one of the cogs of the disc and the steel spring, the current traverses the coil, and no sensible spark, or only a very feeble one, is perceived; but the moment the spring leaves the cog, and on the consequent return of the wire to its natural state, a *reflex wave* of Electricity, moving in a *contrary direction* to that of the battery current, is generated, and a bright spark is produced. Now this bright spark is not occasioned by any direct action of the battery, as Faraday has shown,* but by a force exerted in the wire of communication, that is, in the coil; and if 2 wires, connected respectively with either extremity of the coil, be brought almost into contact, at the very moment that contact with the battery is broken, the spark will appear at the interval between them, while that at the disc will be very feeble; so also, if a fine platinum wire be interposed between the two cross wires, it will remain unaffected as long as the spring and the disc are in contact, but the moment the former leaves one of the teeth of the latter, the platinum wire either fuses or becomes red-hot.

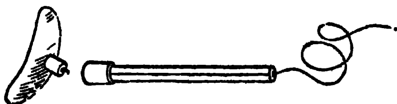
The spark which passes between the cross wires is one of great intensity, and if the body be interposed, a shock, more or less violent according to the size of the coil, is experienced; if a bundle of iron wires be thrust into the axis of the coil, it becomes insupportable. That this *induced* current does really move in a direction *contrary* to that of the battery current, may be proved both by the galvanometer and by chemical decomposition. If a galvanometer of no great delicacy be interposed between the cross wires, it will show a current in the direction of the battery current, as long as the spring remains in contact with the disc, a portion of the Electricity excited by the battery passing through the wire of the galvanometer; but if the needle of the instrument be forced back by pins applied upon opposite sides of its two extremities, so as to retain it in its natural position, when uninfluenced by a current, and if then the spring be caused to leave the tooth of the wheel with which it is in contact,

* See his Experimental Researches, par. 1,078, *et seq.*

the needle will immediately be strongly deflected in an opposite direction, showing evidently that the induced current follows a course *contrary to* that of the battery. Again, if two platinum discs be covered with bibulous paper, moistened with iodide of potassium, and attached respectively to the ends of the two cross wires, a feeble evolution of iodine is *sometimes*, though rarely, obtained during the maintenance of contact, but the moment the spring leaves the cog the salt is decomposed in such a manner as to show the passage of a current in the reverse direction to that of the battery.

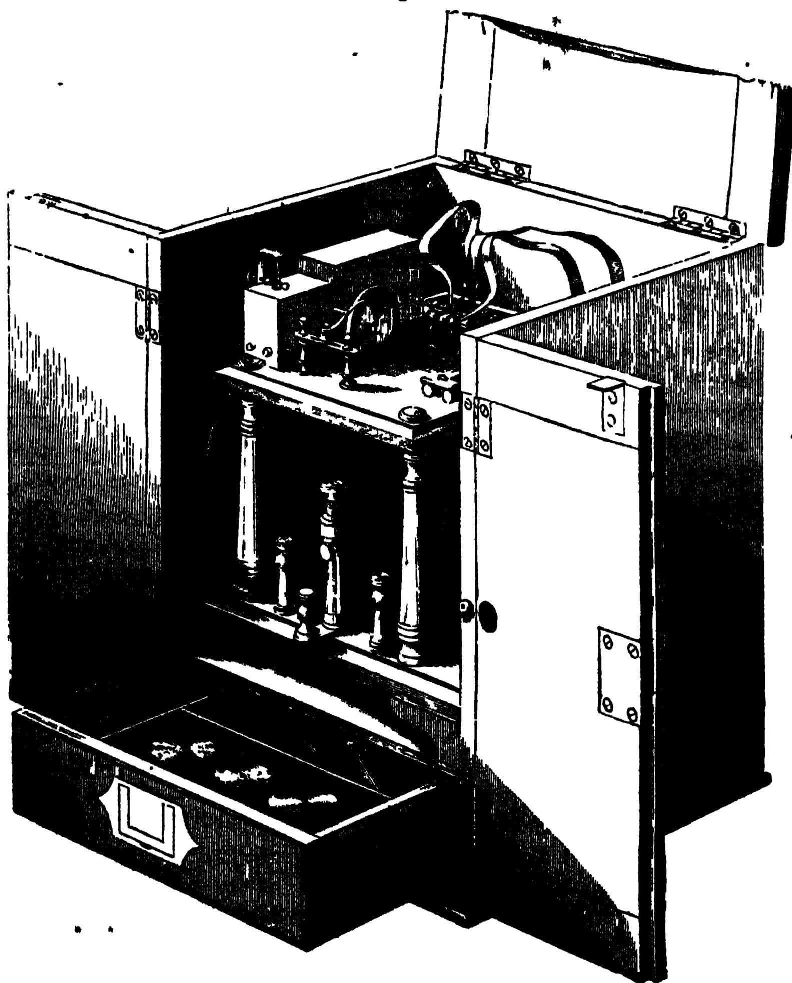
From these facts it will be seen at once that we have in this arrangement of the coil a ready method of administering to a patient, either *direct* or *inverse* shocks at pleasure. In the front of the lower platform in the figure, and between the two supports of the upper stage, will be seen a small water regulator. This is interposed in the circuit of the coil, and by raising or depressing the upper wire, which is done in the most gradual manner by making it a screw, the intensity of the shocks may be modified to any required degree, and such perfect command does this simple arrangement give us over the power of the induced shock, that we are enabled by means of it to apply this form of Electricity to so delicate an organ as the eye, or to administer shocks sufficiently severe to bring a stout man to his knees. The method of connecting the water regulator with the coil will be understood by the slightest reference to the figure. The clock work is so contrived as to give the disc one revolution per minute. Several of these discs are provided each with a different number of cogs, and we have thus a convenient method of regulating the frequency of the shocks. The binding screws are marked respectively A and B, A representing the positive and B the negative pole of the battery; at the moment of making contact, and during the time the current is circulating, not the slightest shock is experienced; but the instant the spring slips over one of the teeth of the disc, the shock passes from B to A. If, then, we wish to administer *direct* shocks to a paralytic limb, say the leg, we apply a sponge director or saddle, moistened with salt water, and connected with B to the hip, a metallic plate in connexion with A being placed in a basin of salt water, and the foot of the patient laid upon it; if, on the other hand, we wish to apply *inverse* shocks, we merely reverse the disposition of the conductors.

Fig. 393.



(1038) *Ruhmkorff's Induction Apparatus.*—In the year 1842, MM. Masson and Breguet constructed a coil with which they

Fig. 394.

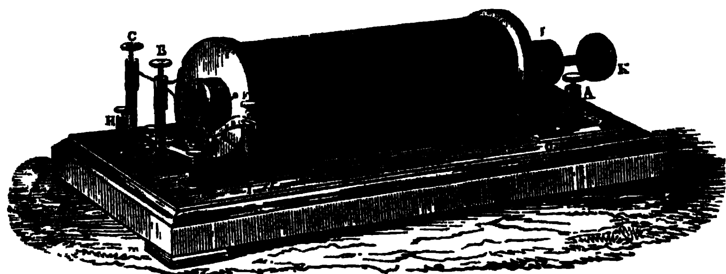


obtained a spark between the terminals of the secondary coil *in vacuo*, and also ignited platinum wire; but from the imperfect way in which the wire was insulated, they could not obtain a sensible spark in free air, though they succeeded in charging a condenser. About the same time, Mr. Hearder, of Plymouth, constructed a powerful arrangement of primary and secondary wires under the form of a medical instrument for which, in September, 1846, he received the silver medal of the Royal Polytechnic Society of Cornwall. With this apparatus surprising electrical effects were produced; strong sparks were obtained *in air*, Leyden jars were charged, and

a striking distance obtained of several inches through rarified air. In 1851, M. Ruhmkorff, of Paris, brought the induction coil to a far greater degree of perfection than it had hitherto attained, by paying the greatest possible attention to the insulation of the secondary wire, which after being covered with silk, was surrounded with a layer of gum lac, and the ends attached to glass columns fixed on the base board of the instrument; he likewise increased considerably the length of the coil, diminishing at the same time its thickness, having found experimentally that the inductive effects of the apparatus are increased in proportion as the number of the spirals is augmented. As thus constructed, the instrument exhibited extraordinary effects: brilliant sparks were not only obtained at the points of disjunction, but also between the wire and a conducting body in communication with the earth, whilst in vacuo a brilliant and continuous stream of *stratified* light was produced. By interposing in the circuit of the primary or inducing wire a single condenser, as recommended by Fizeau, a further augmentation of power was obtained; the sparks in free air were increased to nearly $\frac{3}{4}$ths of an inch in length, and were accompanied by a snapping noise, while the power of the shocks was exalted to such a degree as to be excruciating and even dangerous.*

(1038) The *induction* apparatus as at present constructed by M. Ruhmkorff is shown in Fig. 395. The bobbin is arranged horizon-

Fig. 395.

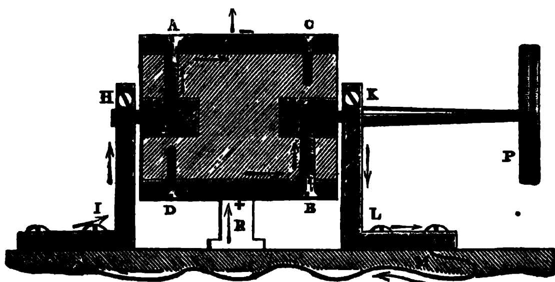


tally; the core is of thin cardboard, and the ends are either of glass or of well varnished wood. The primary coil is a well insulated wire of about ·078 inch in diameter; the secondary is a fine thin wire, the No. 36 of commerce. The extremities of the latter pass through tubes of glass at the end of the bobbin, if the ends are made of wood, but simply through holes drilled in them, if they are of glass. In

* It is stated by Du Moncel (*Notice sur l'Appareil d'Induction Electrique de Ruhmkorff*), that M. Quet was so violently affected by incautiously exposing himself to a shock from the coil, that he was obliged to keep his bed for some time.

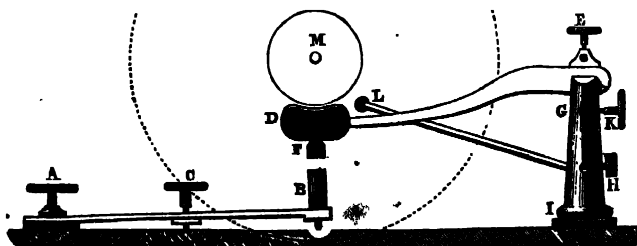
the figure the extremities of the thick coil are attached to the columns I O, while the ends of the fine wire are inserted in the brass caps B C, insulated on glass columns. The wires leading from the voltaic battery are attached to the screws A A on either side of the commutator K, L. Fig. 396. It is composed of a cylinder of ivory supported between 2 copper uprights. On this cylinder are fixed by screws of unequal size, 2 metallic plates A C B D made slightly convex. The largest screws A and B, passing through the ivory, are inserted into the brass cylinders G and E; the smaller screws C D, are merely sunk in the ivory; the copper uprights are in communication with the plates M and O, of the inducing circuits. On turning the button P, suppose the plate B D to be brought into contact with the spring R, in communication with the positive pole of the pile, the current will proceed in the direction of the arrows, entering the cylinder E along B, descending R I, and traversing the coil through M, will re-enter the commutator through O, and rising up H, into the cylinder G, will proceed through the screw A, completing the circuit by A C, in communication with the negative pole. If, on the other hand, the plate B D, touch the spring in communication with the negative pole, it is easy to see that the direction of the current through the coil must be reversed.

Fig. 396.



The *interrupting* apparatus is shown in Fig. 397. M is the fasciculus of iron wires in the axis of the coil, the ends being surrounded by a hoop of polished iron; E D is a lever terminated by a plate of iron D, called the *hammer*; A B is a spring terminated by a massive

Fig. 397.



piece of copper B, called the *anvil.* The screw A is connected with one of the metallic strips which convey the current to the primary coil. The ends B and F, of the hammer and anvil are tipped with finely polished platinum. The end of the lever E D, drops into a slit in the upper end of the column G I; one end of the primary coil enters the column at H. The operation of this interrupter is sufficiently obvious: as long as the anvil and hammer remain in contact the current is closed, but under the influence of this current the fasciculus of iron wires becomes magnetic, and the iron head of the hammer is attracted, the current is thus interrupted, but at the same moment the iron wires lose their Magnetism, and the hammer again falls on the head of the anvil; this act restores contact, the hammer is again attracted by the remagnetized iron, and thus the current is interrupted and renewed with a rapidity the greater as the distance between the hammer and anvil is less.

The Condenser.—This invention of M. Fizeau has been adapted to his coil with great effect by M. Ruhmkorff It consists of 2 sheets of tin foil pasted on either side of a band of varnished silk, about 12 feet long, and folded between 2 other bands of the same silk, the whole being introduced into the interior of the wooden frame of the instrument. The coatings of this condenser are in contact with G H (Fig. 395), where they receive the *extra current.* The function of the condenser is not very clearly understood; according to Fizeau, it condenses and destroys by a *static* effect the Electricity of tension or induction which gives rise to the *extra* current in the induction wire, and which reacts on the induced current in the secondary wire, in a direction, contrary to that of the voltaic current. When the condenser is interposed the interruption spark, is seen to diminish in intensity, that of the induced current on the other hand is greatly increased. According to Faraday the action of the condenser is to diminish the intensity of the inducing current at the moment when it would otherwise produce inconvenient results. At the first moment of the birth of a current in the wire, *lateral* induction is brought about at the expense of the direct induction in the body of the wire, but as soon as the former has attained its maximum, then the latter (that of the wire) becomes proportional to the intensity of the pile. Thus on connecting the two coatings of a Leyden phial by a long insulated wire, and presenting near the points of its attachment to the armatures, the two ends of another wire, so near, that the resistance of the air shall be less than that of the wire, a great part of the discharge will take place across the air; but if the wire be in contact with one of the coatings of a condenser, then no spark will be perceived between the points; and

it is for a similar reason that the spark in the interrupter, in Ruhmkorff's apparatus is sensibly enfeebled. Faraday does not explain the function attributable to this condensation; he only says, that it diminishes the intensity of the inducing current at the moment when it would otherwise produce wasteful results. It does not however, appear in what way this is rendered profitable, in the creation of an induced current, possibly by slackening the rapidity of the passage of Electricity, thereby giving the iron core a more energetic degree of Magnetism.

(1039) According to Poggendorff's view (*Pogg. Ann.*, vol. xciv. p. 2), the function of the condenser is to draw away the Electricity of tension, which when the battery current is interrupted, accumulates at the two ends of the inducing coil, where it would otherwise be retained by the resistance of the air reacting on the fluid set in motion in the thin wire, and so diminishing its intensity. The same result is obtained by uniting the *hammer* and *anvil* by a long thin wire. The condenser does not increase the quantity of Electricity set in motion in the secondary wire, as may be proved by the galvanometer, but it *does* increase vastly the physiological effects. In general, it increases the energy of the apparatus, whenever there is a great resistance set up between the poles; hence the great power it gives to the sparks in free air; while *in vacuo*, where the resistance is small its influence is not seen. For the condenser to continue to act, it must be discharged before every interruption of the current, and this takes place in the form of a visible spark. The hammer then gives a double series of sparks, which though they cannot be separated by the eye, owing to their quick succession, are nevertheless distinguishable in character. The spark, on breaking contact, is always weakened by the condenser, and the degree in which it is so weakened, may be considered as a measure of the condenser's action. These interruption sparks, as well as the discharge sparks, attack the hammer strongly; there is a transfer of platinum from the more highly heated *negative* to the *positive* pole, and if the negative or zinc end of the battery be connected with the hammer, and the positive or platinum end with the anvil, the first only will wear away, and on the plate of the latter there will be a deposit of pure platinum. Instead of a long strip of coated silk, Halske employs as a condenser a single covered sheet of mica, about the octavo size, which he finds to act nearly as well. Poggendorff uses thin waxed paper, covered with a solution of shell-lac, and he found, that a condenser of this substance, or of gutta percha, was as effective, or nearly so with respect to the length of the induction spark, when it contained on each side 4, or 9, or 16 square inches, and that it was nearly as effec-

tive as the long oiled silk of Fizeau. The sole advantage, according to this eminent physicist which the great condensers possessed over the small ones, was that the former gave less noisy sparks than the latter, and that the sparks followed one another more quickly. His experiments were, however, made with the current from *one* or from *two* pairs of Grove's battery; with larger batteries the relations between the actions of the different condensers would be different. The small condensers do not act well when the primary wire is lengthened; in fact, they then become almost useless. With a primary wire ⅔ of a millimetre thick and 1,000 feet long, the condenser of 1 square inch surface was found to be without effect. Again, the action of the condensers depends essentially on the induction coils: when instead of using a very thin induction wire 10,000 feet long, Poggendorff used one of thicker wire, and 2,400 feet long, the small condensers actually *weakened* the sparks between the ends of the wire; on the contrary, the oiled silk large condensers still retained their energy of action, and it was clearly perceptible that the condenser 8 feet long was superior to that 2 feet long. It appears, therefore, that the more intense and energetic the *inner* induction or *extra* current is made, the greater the condenser must be, to obtain the most energetic development of sparks. A most extraordinary fact was discovered by Poggendorff during these researches, viz., that by making the contact breaker act in a partial vacuum, the condenser may be dispensed with, the sparks from the induction coil being quite as strong, indeed in some cases stronger, and the luminous phenomena in the electric egg, quite as well developed without the condenser as with it. Poggendorff thinks that the cause of the action of the hammer in vacuo, is of the same nature with that of the condenser.

(1040) M. Poggendorff (*Annalen*, vol. xciv., p. 2, and *Phil. Mag.*, 1855) divides the coil into several parts, the ends of the wire being made to run out at opposite extremities. If the layers extend without interruption from one end of the coil to the other, the *tension* of the Electricity must increase from the middle towards each extremity, and the lateral passage of sparks is thereby much facilitated. Instead of covering the silked wire with a solution of shell-lac in alcohol, Poggendorff recommends a mixture of wax and oil, or paraffine. He coils the wire round a glass cylinder, at the extremities of which are rings of gutta percha; he then covers it well with wax and binds it to its wooden stand with strong rings of gutta percha. This primary wire is 1 millimetre (·039 inch) thick, each of its halves being 100 feet (French) long.* The secondary or induction coil in

* 1 Paris foot = 12 789 English inches.

one of his instruments is 10,000 feet (Parisian) long, and makes 16,000 windings in 8 parts, each of which contains 33 layers. The diameter of the wire is 0·15 millimetre; the coils are $5\frac{3}{4}$ Parisian inches long, their internal diameter $1\frac{1}{6}$ inch, and external diameter $2\frac{3}{8}$ inches. The induction wire of another coil is 2,400 feet long, each of its parts containing 19 layers; diameter of the wire 0·25 millimetre. Notwithstanding the insulation, internal sparks passed; the phenomena of sparks and tension are described as having been at first wonderful, but after a quarter of an hour, the action decreased considerably. At first with two pairs of Grove's, a spark could be obtained at a distance of 12 millimetres, but afterwards it sunk down to 9·5. It is wrong, therefore, to strain the coil too much, when the current is broken so as to obtain sparks in air, because the Electricity then possesses great tension. When used to take sparks in a partial vacuum, great insulation is not necessary, the tension of the Electricity being much less; and as soon as the resistance of the partial vacuum is small in comparison to that of the induction wire, an increase in the length of the wire does not add anything to the brilliancy of the phenomena. For obtaining sparks in air, and for other phenomena of tension, the most perfect insulation is required, and the thicker the insulating medium the better.

Poggendorff recommends. 1°. That the wire be not less than $\frac{1}{4}$ of a millimetre in diameter. 2°. That it be covered with very thick silk. 3°. That the insulating medium be liquid, such as rectified oil of turpentine. 4°. That the coil, instead of being cylindrical, should have a *solenoid* or spindle shape, because the inducing coil and the soft iron core are most effective in the middle. The soft iron cores he uses are composed of a bundle of wires 0·45 millimetres in diameter; they are heated to redness, cut into pieces of convenient length, bound in a bundle with silk thread, and put into a paper covering. A core 6 inches long and 13 ounces in weight, contains 4,200 wires; but it was found that a hollow core of wire, containing an empty cylindrical space $\frac{3}{4}$ of an inch in diameter, was quite as effective as a solid one, nor was the action of the coil increased when a massive bar of soft iron was introduced into the hollow axis. Under otherwise equal circumstances, the inducing action of a current, just as its magnetic action, is a product of the intensity and length. Hence a short thick wire and great intensity of current may sometimes be advantageously replaced by a long thin wire and small intensity of current.

(1041) *Phenomena of the Induced Current.* 1°. *The Spark in Air* —Taken between two wires of sufficient thickness, it appears under the form of a bundle of 3 or 4 darts of fire, more or less curved, and

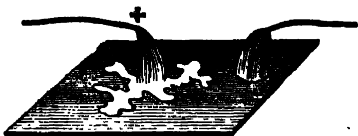
passing between different parts of the *Rheophores;* between larger surfaces the sparks pass at longer intervals, but with greater noise and energy. When the interruptions of the primary are slow, the sparks are longer than when they are rapid, *time* being required for the development of induction. If two zinc wires be used as rheophores and brought within striking distance of each other, the *negative* pole only will become red hot and burn, so that this property may be taken advantage of to determine the direction of the induced current in the place of a galvanometer. It must here be observed that although when the poles of the induction coil are connected by a metallic wire, or by a good conducting liquid, there are *two alternate* currents moving in opposite directions, according to the well known principles developed by Faraday (*Ex. Research.*, x., &c.). Yet, when the poles are separated by a thin stratum of air, *one* only of the two induction currents acts, that namely due to the breaking of the galvanic current; the other, that produced by closing the current is stopped off from the secondary wire, being expended in the primary wire itself. The secondary wire gives then a series of intermitting currents, all of which have a common direction; it has, in fact, *fixed* poles, and chemical decompositions are obtained in accordance with the voltaic law.

As a proof of the difference of electrical tension in the two poles, sparks may be drawn from the *exterior* end of the helix, but not from the *interior;* but by connecting two coils properly together, a current having poles of equal tension may be obtained.

(1042) By attentively watching the spark in the dark, it is seen to be surrounded with a sort of yellow-green atmosphere of greater or less thickness, according to the force of the pile. It is generally of an ovoid form, and seems to be collected principally round the negative pole. It is probably due to the high temperature imparting a luminosity to the circumambient air. A curious appearance is presented when a steady current of air is propelled from the lungs or from a bellows upon the spark taken between two metallic wires, the luminous atmosphere becomes expanded into a large mass of irregular violet-coloured flame, surrounded by bundles of rays, the spark itself not appearing to undergo any variation. The influence of heated air in deviating the spark is well seen by bringing the rheophores in the vicinity of a candle; the spark takes a curved form to get into the flame, though its passage is thereby lengthened; in the centre of the flame, it expands into a sphere of white light. When the rheophores are of unequal size, the darts of fire spread out on the larger surface, especially if this be the negative, the luminous atmosphere then becoming conical. If the negative rheophore be terminated by a large

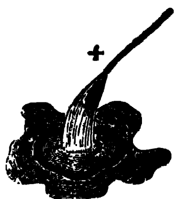
metal plate, the surface of which is either dirty or covered with very fine powder, the positive being simply a wire, the spark spreads over the metal plate like a splash of water, or like the leaves of a tree, the extension varying with the size of the plate. If the negative plate be polished, this appearance is not presented, the spark leaves on the plate the imprint of its passage (*Grove's experiment*, (554), and round the striking point a coloured ring is seen analogous to that produced by heat on a copper plate.

Fig. 398.



In this ring, that surrounding the central point is *blue*, round it is a diffused *brown* ring. If the negative rheophore be in contact with a surface of water, the spark ramifies like the root of a tree, and if a few drops of oil be poured on the water, the root-like rays become terminated with white luminous globules, having the appearance of a tree loaded with fruit. Between charcoal points the light is very brilliant, and when the poles are brought near, quite white, like those between the charcoal terminals of the voltaic battery. *Cork* rendered conducting by immersion in sulphuric acid, or *leather* moistened with acidulated water, gives a still more brilliant light—both the cork and the leather being carbonized and burnt. It is singular that these substances thus once rendered conducting by acid, retain their conducting power for a long time after the acid has evaporated. When one of the terminals is immersed in mercury, the spark is brilliantly white and diffused.

Fig. 399.



(1043) If the coil be vigorously excited with 4, 6, or 8 pairs of Grove's battery, and the spark passed through a glass tube by means of wires hermetically sealed into its sides, and the ends about $\frac{1}{10}$ of an inch apart, *red vapours* are formed in from 10 minutes to $\frac{1}{2}$ an hour, proving that the oxygen and nitrogen have entered into chemical combination. Becquerel and Fremy have proposed this experiment as a test for nitrogen. In condensed air the spark is shorter and more collected, as is the case with ordinary Electricity. In rarefied air, on the contrary, the spark receives a wonderful development, but is less intense in light. In *hydrogen* the spark is feeble and very red; in *carbonic acid* it is vivid and white; in *oxygen and nitrogen*, as in air, perhaps more brilliant in oxygen; in *hydrochloric acid gas*, it has a very characteristic blue tint. *Ozone* may be produced by the induction spark, either directly or indirectly. In the former case the spark is taken between two wires sealed into a tube filled with *pure*

dry oxygen; the sparks must not be continuous, but must succeed one another slowly and gently; before sealing up the tube a strip of paper, covered with starch and iodide of potassium, is introduced—it soon becomes blue (545). In the latter case the sparks must be made to stream over the *outside* of the tube. To succeed in these experiments, no foreign bodies must be present.

(1044) 2°. *The Induction Spark in Liquids.*—In all good conducting liquids, there is, of course, no spark; but in those liquids which conduct either imperfectly or not at all, short crackling sparks are obtained. In *oil* the sparks are greenish white, in *alcohol* they are red and crepitating; brilliant sparks are obtained in *spirits of turpentine* and in *sulphuret of carbon.* If some oil be poured on the surface of water in a glass vessel, and one of the rheophores, covered with gutta percha, introduced beneath the water, and the other immersed in the oil within striking distance, strong crepitating sparks are obtained and hydrogen gas is liberated, which burns on the surface of the liquid. Between a pair of Wollaston's "guarded" poles (211), a continuous light may be kept up in acidulated water, or in solution of sulphate of copper.

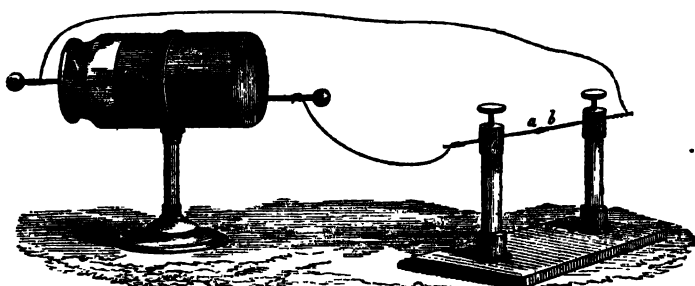
(1045) In the year 1853, M. Masson (*Prize Essay*, Haarlem) made a series of experiments by which he proves that a condenser may be charged by the induction coil machine. He placed the two poles of the coil in connexion with the coatings of the condenser, which coatings he at the same time connected with an insulated Lane's discharger, the balls being $\frac{1}{10}$ of an inch apart; he thus obtained a permanent discharge surpassing in intensity that of the direct discharge of the apparatus in a degree proportional to the size of the condenser and the number of the elements of the pile. Grove and Gassiot have since repeated these experiments on a much larger scale (*Phil. Mag.*, Jan., 1855), and with results of a singularly interesting character. When a pint Leyden phial was interposed between the terminals of the secondary coil, the *exterior* pole being connected with the interior of the jar, the noise and brilliancy of the discharges were greatly increased, but no advantage was gained by increasing the number of the cells of the battery; on the contrary, the platinum contact-breaker was thereby rapidly burnt; when, however a Leyden phial of double the capacity was employed, the brilliancy of the discharge spark was again increased, and on adding more coated surface, a further addition could be made to the battery, with a further increase in the effects, and without any injurious action taking place at the contact breaker. With a powerful apparatus in the possession of Mr. Gassiot, as many as 30 battery cells and 5 square feet of coated surface were used; the effects were very

striking—a roar of voluminous discharge 0·6 of an inch long, increased to 1·5 inch when the flame of a spirit lamp was placed between the terminals. "I have never," writes Mr. Grove, "witnessed such a torrent of electrical discharges—the noise could not be borne long without great discomfort. . . . It is very curious to see the *absorption*, so to speak, of the voltaic power by the Leyden battery: when the maximum effect for a given Leyden jar has been passed, the contact breaker shows by its sparks the unabsorbed induced Electricity, which now appears in the primary wire; an additional jar acts as a safety-valve to the contact breaker, and utilitizes the voltaic power, and so on."

(1046) The difference between the ordinary induction spark and that produced when the secondary terminals are connected respectively with the inner and outer coating of a Leyden jar is very striking; in the former case it is flame-like, soft, and quiet; in the latter, it is bright, sonorous, and apparently large; but while the rattling spark cannot fire wood, paper, or even gunpowder, the soft spark at once inflames either of them. The effect of the static induction thus introduced is not so much to vary the *quantity* of Electricity which passes, as the *time* of the passage. That Electricity which, moving with comparative slowness through the great length of the secondary coil, produces a spark having a sensible duration (and therefore in character like that of a Leyden jar passed through a wet thread) is when the jar is used, first employed in raising up a *static induction* charge, which, when discharged, produces a concentrated spark of no sensible duration, and therefore much more luminous and audible than the former. The following experiment of Faraday (*Notices of the Meetings of the Royal Institution,* June 8, 1855) well illustrates this difference in the character of the two sparks: A piece of platinum wire is fixed horizontally across the ball of a Leyden jar, and the platinum wire secondary terminals brought respectively near its ends; two interruptions are thus produced in the secondary circuit, the sparks at which are like each other and equal in quantity of Electricity, the jar as yet forming only an insulating support. But if, in addition, either secondary terminal be connected by a wire with the outside of the jar, the spark on that side assumes the bright loud character before described, but ceases to fire gunpowder or wood; and no one would at first suppose—what is really the case—that there is the same Electricity passing in one as in the other. If one of the secondary terminals be connected with the outside of the Leyden jar, and the other be continued until near the knob, a soft spark appears at that interval for every successive current in the primary circuit. This spark is,

however, *double;* for the Electricity thrown into the jar at the moment of induction is discharged back again at the same place the instant the induction is over. The first discharge heats and prepares the air there for the second discharge, and the two are so nearly simultaneous as to produce the appearance of a single spark to the unaided eye. In all these experiments the exterior pole of the induction wire must be in contact with the knob of the jar; if, however, the jar be insulated as in Fig. 400 it is immaterial which way the

Fig. 400.

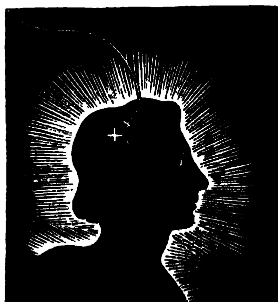


connexions are made. The discharge takes place between *a* and *b*, and a strip of writing paper moved slowly across the line of discharge will become punctured with a row of holes, which will be the more closely approximated in proportion as the succession of discharges is more rapid. When *two coils* are properly connected together through their primaries and secondaries, and a battery of from 10 to 15 cells of Grove employed, the extent of coated surface may be increased to 7 square feet, and the discharges are then most magnificent, fully ·75 of an inch in length, piercing stout card, and accompanied by an almost insupportable noise.

(1047) *Transmission of the Induced Current through Rarefied Air—Gassiot's Cascade.*—Perhaps the most beautiful experiment that can be made with the induction coil is the following, described by Mr. Gassiot (*Phil. Mag.*, vol. vii., p. 854). Two-thirds of a beeker, 4 inches deep by 2 inches wide, are coated with tin foil, leaving 1·5 inch of the upper part uncoated. On the plate of an air-pump is placed a glass plate, and on it the beeker, covering the whole with an open-mouth glass receiver, on which is placed a brass plate having a thick wire passing through a collar of leathers; the portion of the wire within the receiver is covered with a glass tube; one end of the secondary coil is attached to this wire, and the other to the plate of the pump. As the vacuum improves, the effect is truly surprising: at first a faint, clear blue light appears to proceed from the lower part of the beeker to the plate, this gradually becomes brighter,

until by slow degrees it rises, increasing in brilliancy until it arrives at that part, which is opposite, or on a line with the inner coating, the whole being intensely illuminated; a discharge then commences from the inside of the beeker to the plate of the pump in minute but diffused streams of blue light; continuing the exhaustion, at last a discharge takes place in the form of an undivided continuous stream, overlapping the vessel, as if the electric fluid were itself a material body running over. If the position of the beeker be reversed by placing the open part on the plate of the air-pump, and the upper wire is either in contact or within an inch of the outside of the vessel, streams of blue lambent flame appear to pour down the sides to the plate, while a continuous discharge takes place from the inside coating. The following experiment is also a very beautiful one: cut out a design, such as a letter, a star, or a head, on a piece of tin foil, and paste it on a thin piece of glass or talc; paste an entire piece of foil on the other side also, connect the latter with the negative pole of the coil, and by means of a glass rod bring the positive pole into contact with the figure, which, in the dark, will become brilliantly illuminated, throwing out on all sides long rays of blue light, which may be increased by blowing gently upon it.

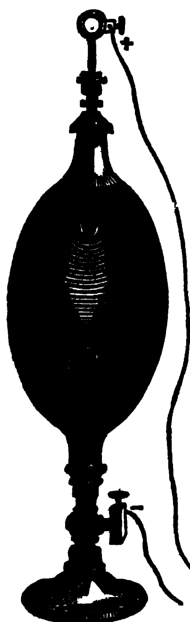
Fig. 401.



(1048) Mr. Grove, in his investigations to determine the electro-calorific effects due to the polar reactions of induced currents on metallic plates (556), made among other experiments the following. He put a piece of carefully dried phosphorus in a little metallic cup, and covered it with a receiver having a cap and wire; on making a good vacuum, instead of a simple diffused light, he obtained a light completely stratified, that is to say, divided transversely to the direction of the jet by a multitude of very straight and mobile dark bands. About the same time (*Th. Du Moncel*) Ruhmkorff noticed the same phenomenon in an *alcohol* vacuum, viz., magnificent vibrating stratifications in the middle of the red light issuing from the positive pole. These phenomena were studied in 1852 by M. Quet (*Compt. Rend.*, Dec. 1852). When the poles are about 3 or 4 inches apart in an excellent vacuum produced in the electric egg (Fig. 402), two distinct lights are produced differing in colour, form, and position; that round the negative ball and wire is blue—it envelopes it regularly; that round the positive is fire-red—it adheres to one side and stretches across towards the negative, and has for its lateral

limits a surface of revolution about the axis of the receiver. On close examination this double light is seen to have a singular constitution: it is stratified, being composed of a series of brilliant bands separated from each other by dark bands. These are best observed in vacua of wood spirit, spirit of turpentine, alcohol, naphtha, and bichloride of tin, and the vacuum must be as perfect as the best air-pump can make it The appearance is then that of a *pile* of electric light. In the red light, the brilliant bands approaching nearest to the negative ball have the form of capsules—the concave part being turned towards the ball; their position and figures are sensibly fixed, so that it is easy to see that there is a rotation of continuity in passing from one to the other. The extreme capsule does not touch the violet light of the negative pole, being separated from it by a dark band, greater or less according to the nature and perfection of the vacuum, that with spirit of turpentine giving the greatest. Fig. 402 presents an accurate representation of this singularly beautiful phenomenon.

Fig. 402.



(1049) There are a multitude of bright beds in the red light, varying in colour and form according to the media, the degree of exhaustion, and the distance between the balls, the greatest variety being with bichloride of tin, but they are not fixed in position. If the balls are some distance apart they have an undulating motion, if nearer they seem to have a gyratory movement round the axis of the receiver. Since the two stratified lights of red and blue are in most vacua separated by a dark red band, M. Quet thought that by approaching the two balls nearer to each other, one of the lights might be extinguished while the other was preserved, and this actually was the case in an *air vacuum* when the positive ball was well polished, but in those vacua in which the red light is excessively developed round the positive ball the extinction is not complete. In all cases the blue light so far from disappearing or becoming weaker when the red light has disappeared, is considerably extended. M. Quet found that when a galvanometer was interposed at the circuit, no current was indicated as passing through the electric egg till the exhaustion was tolerably good, and the light continuous; the needle then became permanently deflected. The first light that appeared was the red round the

positive ball, but it is not until the exhaustion becomes very perfect, that the blue light becomes well developed and extended round the negative wire; if then the two balls be brought nearer together, the deviation of the needle of the galvanometer sometimes reaches 80°. Thus the facility of the transmission of the induced currents depends on the perfection of the vacua and the distance between the balls.

(1050) Grove's beautiful experiment with phosphorus is made in the following manner: A small piece of perfectly dry phosphorus is placed in a small platinum capsule, on the lower ball of the electric egg; to keep the receiver dry, a stick of caustic potash is suspended in a tube from the upper wire, the exhaustion is then made as perfect as possible, when the crimson light becomes gradually furrowed with beautiful stratifications, through a length which may be extended to 12 inches; and when once obtained, the experiment may be stopped, and after 20 minutes or more, resumed with more brilliancy than before. The cause of these stratifications is not at present known, but they depend, not only on the nature of the vapour, but on the form of the receiver, and the tension of the current. With a battery of 30 pairs of Grove, they cannot be obtained at all, the receiver being then filled with a brilliant white light.

Fig. 403.



A light (though less red and brilliant) may be obtained from one pole only, that of the exterior wire, which, as we have seen, possesses Electricity of the greatest tension; and if the vacuum be very good, this light may be made to bifurcate by placing the finger against the outside of the glass, as shown in Fig. 403.

If a considerable resistance be introduced into the induced circuit, or if the two currents are made to circulate in opposite directions through the receiver, the red light disappears from the positive pole, giving place to a blue light; the positive and negative lights are now the same, the appearance in the egg being as represented in Fig. 404. According to Masson, a proof is here afforded of the circulation of two currents moving in *opposite directions* along the same wire. Gaugain refers the phenomenon to an action of resistance, charge and discharge taking

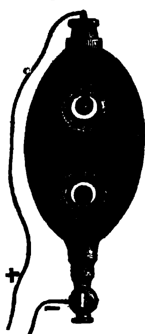


Fig. 404.

place across the induced wire without any passage of the current. The resistance alluded to may be best accomplished by interposing a condenser between one of the rheophores and one of the balls of the egg. A uniform blue light is thus obtained round both balls, which with a good exhaustion may be stratified.

In the Torricellian vacuum the induction spark is white, filling the whole tube.

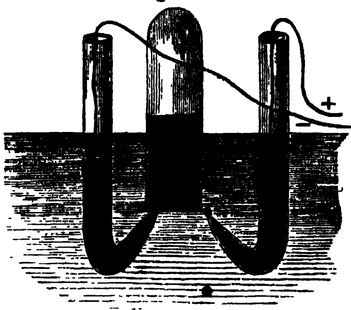
(1051) *Transmission of the Induced Current across Secondary Conductors.*— Certain substances, such as very thin metallic leaves and powdered charcoal are sufficiently good conductors to allow the passage of electricity, but not without the phenomena of light. A good way of exhibiting the action of secondary conductors with the Ruhmkorff coil is to employ a gilt-edged book; sparks from 1½ to 2 inches long may thus be obtained. It is also shown in a very brilliant manner by sprinkling finely powdered metallic dust on a varnished board; induction sparks, or rather *furrows of fire*, 2 or 3 inches long, may thus be obtained; with fine copper filings the colour of the fire is yellow green; with zinc it is blue, with iron red; and with steel scintillating. Another method is to smear a drop of water with the finger over a varnished board, and to pass the spark across it; it is thus obtained very brilliant, the colour depending on the thickness of the stratum. The part played by the vapour of water, rain, and currents of air unequally dilated, acting as secondary conductors, is evidently very important during storms; they facilitate the passage of the lightning, the great length and zigzag character of which may thus be explained.

(1052) The luminous spectrum produced by taking the spark from the induction coil between different metals has been studied by Masson (*Memoires de l'Academie de Haarlem*, 1853). Between *cadmium* terminals the blue and green rays were beautifully developed, more beautifully perhaps than with any other metal; *antimony and bismuth* gave brilliant rays of a pure white colour; *lead* was remarkable for the great extension of the violet part of the spectrum, and for the great beauty of the rays given by this colour; *zinc* was characterized by the extent of the apple-green colour of its spectrum; *silver*, by the surpassing brilliancy of green; *gold* was more yellow than silver, and *carbon* emitted a multitude of remarkably brilliant rays.

(1053) *Chemical Effects of the Induced Current*:—The induced currents of the secondary coil may produce two distinct chemical effects, according as they pass along the electrolyte in the state of

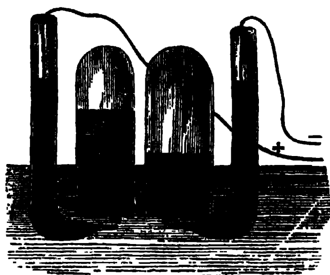
luminous discharge, or in the state of *dark* discharge. In the latter case the decomposition is *electrolytic;* but in the former, the medium across which the discharge takes place, is highly heated in the vicinity of the poles; *here* alone, therefore, the decomposition takes place, and the gases are mixed. M. Masson calls this kind of decomposition *photo-electric*, the former being *polar*. According to Grove, in the photo-electric decomposition of water there is excess of hydrogen when the water is only feebly acidulated or alkalized; when the water is rendered a better conductor, the excess of hydrogen vanishes; and after it has reached its maximum of conducting power there is excess of oxygen.

Fig. 405.



In order to produce a decomposition of water, such that the two gases shall be mixed at both poles, a pair of Wollaston's guarded points (211) must be used, the wires not projecting beyond the glass; sparks then pass. If one of the wires be soldered to a small plate of platinum (Fig. 405) all the action is concentrated on the other wire, and now we have an evolution of the mixed gases at one pole only

Fig. 406.



To produce true polar decomposition, the platinum wires must project beyond the glass tubes, as shown in Fig. 406.

Therapeutical Applications of the Induction Coil Apparatus.— The induction shock being exceedingly violent, great care is required in administering it; it should never be attempted without a water regulator. The *inner* end of the wire is kept in permanent contact with the body of the patient, and the operator excites the spark with the exterior pole; or sparks may be excited by simply touching the part to be electrized with the exterior pole, the patient not touching the inner end of the wire, in which case no water regulator is required. When the current is employed, it must be graduated most carefully, which may be done by interposing greater or less resistances. If the rheophores are very fine wires, the points alone being applied to the part affected, the shocks are infinitely weaker than when metallic plates or wet sponges are used. To avoid, however, the calorific effects, it is better to employ for the rheophores

small glass tubes filled with water, the points being filed off. In extreme cases, such as in asphyxia, and in obstinate cases of paralysis, the condenser may be employed. Supplementary rheophores are then put in contact with the coating of a Leyden jar and the other wires used for transmitting the shock through the patient.

Very energetic, but not painful, muscular contractions may be obtained by circulating through the fine wire of the apparatus the current from a small battery of 8 pairs of Daniell's cells; the physiological action is then entirely due to the *extra* current, that is to the reaction of the voltaic current on itself. To one of the poles of the secondary, one of the rheophores of the pile is attached; to the other pole is fixed a wire terminated by a sponge, plate, &c.; the other rheophore of the pile is attached to another plate or sponge. These two plates or sponges are then applied to the part to be electrized, and contacts are broken and renewed by the hand holding an insulated wire.

(1054) Since the foregoing observations upon this interesting apparatus were written, we have had an opportunity of comparing Ruhmkorff's instrument with one constructed by Mr. Hearder of Plymouth. The bobbin upon which the wire of this coil is wound is 6 inches in length, the coil itself being about 4½ inches thick. The quantity of secondary wire is about 3,000 yards (No. 35). The length of the primary is so adapted to the electro-motive force of the battery, as to enable it to develope in the iron core the highest amount of magnetic power; the energy of the instrument depending according to Hearder's view entirely on the degree of magnetization of the iron, and being quite irrespective of any peculiar arrangement of the primary wire. The iron core is, as in Ruhmkorff's instrument, a bundle of small wires capped with solid ends, through one of which passes transversely to the axis an iron adjusting screw serving to regulate the distance between the end of the core and the iron armature on the end of the vibrating spring, which acts as the contact breaker. This spring is a very strong one, having a platinum stud in the middle of its length, which makes contact with a platinum spill below; the spring being strong, and the armature heavy, the vibrations are rapid, and the contacts very firm. The sparks between two platinum terminals followed one another with great rapidity through *five-eighths* of an inch *in air*, the primary wire being excited by 4 cells of Grove's battery; the discharge *in vacuo* was very magnificent through several inches, though (contrary to the statement of Poggendorff), when the conductor was turned off, a very feeble discharge through not more than two inches could be obtained. When a Leyden jar containing 3 square feet of coated glass was

interposed in the circuit of the secondary, as in Fig. 400, a battery of 10 cells being employed, a remarkably sonorous and vivid discharge was maintained in an uninterrupted manner. The noise of the discharge was decidedly greater, and the light more voluminous and bright than with Ruhmkorff's instrument similarly excited.

(1055) In adapting the condenser to his induction coil, Hearder has been guided by considerations derived from a laborious course of experiments. He found that the action of the condenser depends much upon the arrangement of the primary wire, and that with certain modifications of this element the action of the condenser is much diminished; for example, supposing only *one* wire to be used, the amount and intensity of the current induced in this wire will be in proportion to the number of its convolutions, and the magnetic intensity of the core inducing upon it. Accordingly, when a long primary wire is used, and a voltaic current is passed through it capable of developing a high magnetic intensity in the core, the *secondary* current, on the interruption of the circuit, is possessed of so high an amount of electrical tension that a *static* spark immediately passes between the ends; but if these ends be respectively connected with the opposite coatings of a condenser, the static intensities are exerted in charging the latter, by which the tension is so far reduced that the spark is now unable to overleap the distance, and the electric current is thus made to react upon itself, the coatings acting, as it were, like two springs. Now, if the *length* of the primary wire be increased, maintaining at the same time its conducting quality by increasing its *size*, the secondary current soon acquires intensity enough to break through the non-conducting medium of the condenser, and strong discharges can be heard in the interior, and this took place when the condenser consisted of 30 square feet of coated oiled silk, arranged either as one large condenser or in the form of three smaller ones connected together. It was found, moreover, that the increased action of the secondary wire did not bear the same ratio to the increase of battery power *after* the sparks had begun to appear in the condenser as it did *before*. From these results it would appear that we should not endeavour to increase the effect of the machine by an *intensity* battery and a long primary coil: but rather by a *quantity* battery, consisting of a few large elements and a shorter but stouter wire, which will give the same available magnetic intensity in the core for the production of the current in the *secondary* wire without developing in the *primary* wire a current too great for the condenser to dispose of.

The shock which the condenser gives to the system, when the hands are applied to the coatings, increases with its size, and is at

times exceedingly violent; whilst the primary wire, without the condenser, scarcely gives a shock that is appreciable. Hearder constructs his secondary coil independent of the primary, by which arrangement he is enabled to use different lengths and thicknesses of the latter to suit different arrangements of the voltaic battery, as for instance, a short stout coil for a quantity battery, and a longer and thinner wire for batteries containing a greater number of smaller elements. In the insulation of his wire he does not cement the whole together with melted shell-lac, so that he can at any time wind off the secondary for the purpose of examining any defects in it, or for altering its arrangement. He finds common cartridge paper an excellent material for the condenser.

CHAPTER XX.

THE ELECTRIC TELEGRAPH.

History—Lesage—Lomond—Reiser · Salva—Ronalds—Soemmering—Ampere—Gauss and Weber—Steinheil—Morse—Alexander—Cooke and Wheatstone—The five-needle Telegraph—The single-needle Telegraph—The double-needle Telegraph—The earth circuit—The magneto-electric Telegraph—Henley—Bright—The French Telegraph—Froment—Electro-magnetic clocks—Bain—Shepherd.

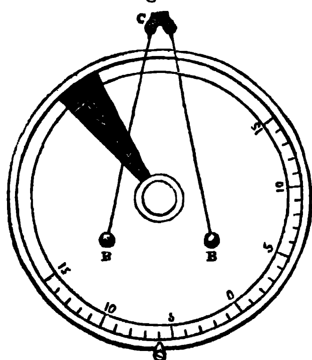
(1056) *The Electric Telegraph.* — The idea of employing Electricity as an agent to effect communication between distant places, is of no recent date; for almost as soon as it became known that conducting wires had the power of transmitting Electricity instantaneously through distances of several miles, it occurred to several Electricians, that correspondence between distant parties might be accomplished by electric action. In 1747, Dr. Watson, Bishop of Llandaff, with several other philosophers, made experiments at Shooter's Hill, which showed that electrical discharges from a Leyden jar could be propagated through a distance of upwards of 4 miles, without any appreciable loss of time, although a considerable portion of the circuit was formed of land and water. The success of these experiments appears to have given rise to the first ideas of forming electric telegraphs, by means of which distant parties might hold correspondence. From the time that Dr. Watson made his experiments at Shooter's Hill, there have been many contrivances for applying electric agency to telegraphic communication. Before 1750, Winkler, at Leipsic, discharged Leyden jars through very long circuits, in some of which a river formed a part; Le Monnier, at Paris, produced shocks through 12,789 feet of wire; and it is said that Betancourt, at Madrid, discharged electric jars through a distance of 26 miles.

(1057) The first distinct proposition to employ Electricity as a mode of telegraphic communication, appears to have originated with Lesage, who, in the year 1774, established in Geneva an electric telegraph consisting of 24 metallic wires, well insulated from each other, and each in communication with a small pith ball electrometer, which could be diverged by an electrical machine, and caused to point to a letter or any other conventional signal; and by this means a communication between two distant places was proposed to be established. A few years later, M. Lomond (Young's "Travels in France," vol. i., p. 212) suggested the employment of a single pith

ball electrometer; and in 1794, Reiser, a German, invented a telegraph in which signals were transmitted by electric discharges sent through strips of tin foil, in which were breaks, so arranged as to represent letters, which became illuminated by the discharge, as in Fig. 46, p. 82. Cavallo, in his Treatise on Electricity, published in 1795 (vol. iii., p. 285), proposed to transmit signals by the inflammation of various combustible or detonating substances, such as gunpowder, phosphorus, phosphuretted hydrogen, &c., by the discharge of a Leyden phial; and in 1787, Betancourt tried similar experiments in Spain.

(1058) The following report on a telegraph invented by Dr. Salva occurs in the *Gazette de Madrid*, Nov. 25, 1796:—"The Prince de la Paix having learnt that M. de F. Salva had read at the Academy of Sciences a memoir on the application of Electricity to telegraphic purposes, and presented at the same time an electric telegraph of his own invention, wished to examine it; and charmed with its promptitude and the facility of its operations, he showed it afterwards to the King and to the court, when it performed equally well. After this experiment, the Don Antonio wished to obtain a more perfect telegraph, and undertook a calculation of the force of the Electricity required to work a telegraph at different distances under land and water. The *Magazin de Voight*, in reference to these experiments, announced two years afterwards that Don Antonio constructed a telegraph upon a very grand scale, and to a very great extent. It adds, that the prince was informed *at night*, by means of his telegraph, of news that highly interested him."

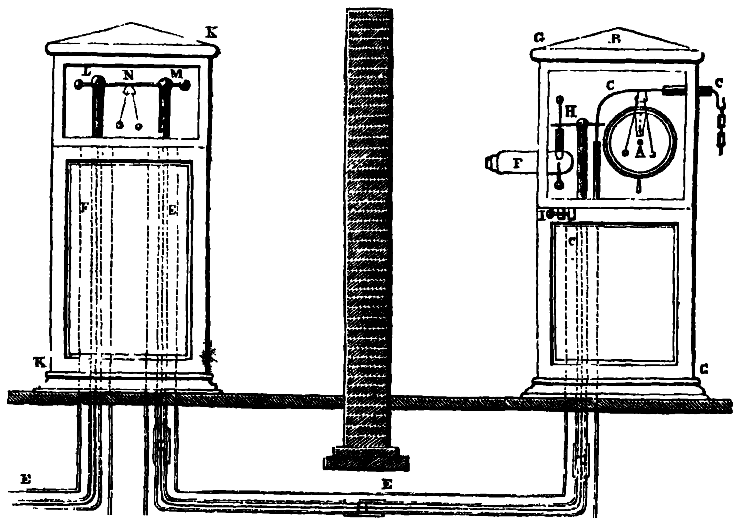
Fig. 407.



(1059) In 1816, Mr. Ronalds, of Hammersmith, invented and constructed an electric telegraph, of which he published a full description in 1823. A light circular brass plate, divided into 20 equal parts, was fixed upon the seconds' arbor of a clock which beat dead seconds. Each division was marked by a figure, a letter, and a preparatory sign. The figures were divided into two series, from 1 to 10, and the letters were arranged alphabetically, leaving out J, Q, U, W, X, Z. Before and over this disc was fixed another brass plate (Fig. 407), capable of being occasionally moved by the hand round its centre, and which had an aperture of such dimensions, that whilst the disc was carried round by the motion of the clock, only

one of the letters, figures, and preparatory signs upon it could be seen through the aperture at the same time; for instance, the figure 9, the letter V, and the sign "Ready," are now visible through the aperture in Fig. 407. In front of this pair of plates, A (Fig. 408), was suspended an electrometer of Canton's pith balls, from a wire C, which was insulated, and communicated with a cylindric electrical machine of only 6 inches in diameter, and with the wire, E

Fig. 408.



525 feet long, which was insulated in glass tubes, surrounded by a wooden trough filled with pitch, and buried in a trench cut 4 feet deep in the ground.

Another similar electrometer was suspended in the same manner before another clock, similarly furnished with the same kind of plates and electrical machine. This second clock and machine were situated at the other end of the buried wire, and it was adjusted to go as nearly as possible synchronously with the first. Hence it is evident, that when the wire was charged by the machine at either end, the electrometers at both ends diverged; when it was discharged suddenly at either station, they both collapsed at the same instant; and when it was discharged at the moment when a given letter, figure, and sign on the lower plate of one clock appeared in view through the aperture, the same figure, letter, and sign appeared also in view at the other clock; and that by such discharges of the wire at one station, and by noting down the letters, figures, or signs in *view* at the other, any required words could be spelt, and figures

transmitted. But by the use of a telegraphic dictionary, a word, or even a whole sentence, could be conveyed by only 3 discharges, which could be effected, in the shortest time, in 9 seconds, and, in the longest, in 90 seconds, making a mean of 54 seconds. This dictionary consisted of 10 leaves, cut in the manner of a common-place book, or ledger; each leaf was also divided into 10 columns, and each column numbered on the top of the page. The columns were intersected by 10 horizontal lines, each numbered on the left side; the space produced by the intersections was occupied by words or sentences.

It was necessary to distinguish the preparatory signs from those intended to spell or refer to the dictionary, by giving the wire a rather higher charge than usual, and thus causing the pith balls to diverge more; and it was always understood that the first sign, viz., "*Prepare*," was made when that word, the letter A, and figure 1, were in view at the communicator's clock; so that should the communicant's clock not exhibit the same sign (in consequence of its having gained or lost more than the communicator's), he noted how many seconds it had lost or gained, and moved his upper plate on its centre through just so many seconds to the right or left as occasion required, and the communicator continually repeated his sign "Prepare," until the communicant had adjusted his clock, and had discharged the wire at the moment when the word "Ready," appeared in view.

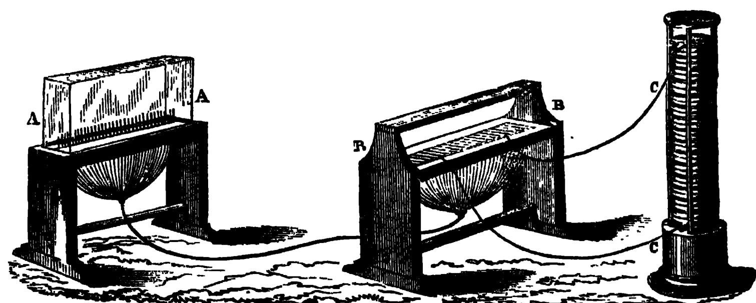
A second preparatory sign was now made by the communicator, provided that the word or sentence was not contained in the dictionary, or that the figures were to be noted, not as referring to the dictionary, but in composition; and this was done by discharging the wire at the moment when the term "Note Letters," or "Note Figures," came into view. The gas pistol, F, Fig. 408, which passed through the side of the clock-case, G, was furnished with an apparatus, H, by means of which a spark might pass through it when the communicator made the sign "Prepare," in order that the explosion might excite the attention of the communicant, and the handle, I, enabled him to break the connexion of it with the wire when necessary.

At half the distance between the two ends of the wire was placed the apparatus, K, by which its continuity could be broken at pleasure, for the purpose of ascertaining (in case any accident had happened to injure the insulation of the buried wire) which half had sustained the injury, or if both had. It is seen that the two portions of the wire and tube rose out of the earth, and terminated in two clasps, or forks, L and M, and the wire, N, carrying a pair of

pith balls resting on these forks, connected them. Now, by detaching this connecting wire from the fork L, whilst it still remained in contact with the fork M, or *vice versâ*, it could be seen which portion of the wire did not allow the balls of the electrometer to diverge, and, consequently, which had lost its insulation, or if both had. One of the stations was situated in a room over a stable, and the other at the end of a garden, a distance of 525 feet, and the wire was buried under a gravel walk. It does not appear that Mr. Ronalds ever tried to work his telegraph at greater distances, for on communicating his discovery to the Admiralty, he was informed "that telegraphs of any kind were then wholly unnecessary, and that no other than the one then in use would be adopted." (See his pamphlet, p. 24.)

(1060) The first electro-chemical telegraph was that of Soemmering, thus described by him in 1812:—"My telegraph was constructed and used in the following manner: In the bottom of a glass reservoir containing acidulated water AA, (Fig. 409), are 35 golden points or pins passing up through the bottom of the glass; each pin corresponded to one of the letters of the alphabet and to the ten numerals. The 35 points are each connected with an insulated copper wire soldered to them, and extending to the distant station BB, where they are soldered to 35 brass plates fixed transversely on a wooden bar; through the front of each of the plates there is a small hole for the reception of 2 brass pins, one of which is connected

Fig. 409.



with the positive, and the other with the negative pole of a voltaic pile, CC. Each of the 35 plates is arranged to correspond with the arrangement of the 35 gold points in the glass reservoir, and are lettered accordingly. When thus arranged, the two pins from the column are held one in each hand; and the two plates being selected, the pins are then put into their holes and the communication is established; gas is evolved at the two distant corresponding

points in an instant; the peg on the hydrogen poles evolves hydrogen gas; and that on the oxygen pole, oxygen gas. In this way every letter and numeral may be indicated at the pleasure of the operator. The following rules should be observed:—

"*First.* As the hydrogen gas evolved is greater in quantity than the oxygen, therefore those letters which the former gas represents are more easily distinguished than those of the latter, and must be so noted. For example, in the words ending *ak*, *ad*, *em*, *ie*, we indicate the letters *A*, *a*, *e*, *i*, by the hydrogen: *k*, *d*, and *e*, on the other hand by the oxygen poles.

"*Second.* To telegraph two letters of the same name we must use a unit unless they are separated by a syllable. For example—the word *anna* may be telegraphed without the unit, as the syllable *an* is first indicated, and *na*. The word *nanni*, on the contrary, cannot be telegraphed without the use of the unit, because *na* is first telegraphed, then come *nn*, which cannot be indicated in the same vessel. It would, however, be possible to telegraph even three or more letters at the same time by increasing the number of wires from 35 to 50, which would very much augment the cost of construction and the care of attendance.

"*Third.* To indicate the conclusion of a word the unit 1 must be used; therefore, it is used with the last single letter of a word, being made to follow the ending letter. It must also be prefixed to the letter commencing a word, when that letter follows a word of two letters only. For example, *sie*, *lebt*, must be represented *si*, *e*1, *le*, *bt*, that is the unit 1 must be placed after the first *e*. *Er*, *lebt*, on the contrary, must be represented *Er*, 1*l*, *eb*, *t*1; that is the unit 1 is placed before the *l*. Instead of using the unit, another signal may be introduced—the cross † to indicate the separation of syllables."

(1061) Suppose now the decomposing table is situated in one city and the pin arrangement in another, connected with each other by 35 continuous wires extending from city to city. Then the operator with his voltaic column and pin arrangement at one station, may communicate intelligence to the observer of the gas at the decomposing table of the other station.

The metallic plates with which the extended wires are connected, have conical-shaped holes in their ends; and the pins attached to the 2 wires of the voltaic column are likewise of a conical shape, so that when they are put in their holes there may be a close fit, preventing oxidation and producing a certain connexion. It is well known that slight oxidation of the parts in contact will interrupt the communication. The pin arrangement might be so contrived as to use permanent keys, which for the 35 plates or rods would require

70 pins. The first key might be for hydrogen A, the third key for hydrogen B, the fourth key for oxygen B, and so on. Schweigger proposed to diminish the number of signals by employing 2 piles, one considerably stronger than the other, sometimes using one, sometimes the other and at other times both combined. By varying the amount of gas given off in a given time—by varying also the periods of time, the number of wires might be reduced from 35 to 2, and the construction of the telegraph thus much simplified. A method of permanently recording the signals was also indicated by Schweigger, which was in principle nearly identical with a plan subsequently employed by Wheatstone, viz., by stamping the letters on paper covered with red-lead or lamp-black. Coxe of Philadelphia (*Thompson's Annals of Philosophy*, 1810) also suggested the employment of the pile to indicate signals. He gives two methods—one by the decomposition of water, and the other by that of metallic salts.

(1062) Oersted's grand discovery of Electro-magnetism was made in 1819, and the first proposal to apply this discovery to telegraphic purposes was that of Ampère, who, in a memoir presented to the Royal Academy of Sciences in Paris, on the 2nd of October, 1820, announced the practicability of an electric telegraph constructed with magnetic needles surrounded by coils of wire. He says (*Annales de Physique et de Chimie*, xv. p. 72): "The success of this experiment demonstrates that by employing as many conducting wires and magnetic needles as there are letters, and by placing each letter under a different needle, signals may be communicated by a pile placed at a long distance off. The communication between the pile and the different coils was to be opened and shut by means of a set of keys. In 1832, Baron Schilling constructed at St. Petersburg, an electric telegraph consisting of a certain number of platinum wires, insulated and bound together with a silk cord, which set in motion by means of a key connected with a galvanic pile, five magnetic needles placed vertically in the centre of the coil. The motion of one of the needles at the commencement of the signalling, caused a leaden weight to fall, the concussion of which set in action a clock-work alarum. This telegraph was exhibited before the Emperor Alexander, but Schilling died before he had perfected or extended his invention.

(1063) The first report of the electric telegraph experiments of MM. Gauss and Weber is to be found in the *Scientific Publications of Göttingen* for 1855, and in *Schumacher's Annuaire* of 1836. Instead of the galvanic pile they employed the magneto-electric machine to give motion to the magnetic needle, which was enclosed in a coil composed of 3,000 feet of wire. By means of a com-

mutator the needle could be deflected in either direction, and its movements were observed with the aid of a lens. This telegraph was actually worked at a distance of one mile and a quarter, viz., between the "Cabinet de Physique" of the University of Göttingen and the Observatory.

(1064) Steinheil's telegraph was at work in July, 1837. A full description of it was communicated to the Academy of Sciences at the meeting of the 10th September, 1838. It was a printing and a sounding telegraph, and was worked like that of Gauss and Weber, by the magneto-electric machine; only one wire was employed, the earth being used to complete the circuit. To communicate signals by sound, Steinheil used two bells of different tones, either of which could be struck at pleasure by the needles; and to make a permanent record of a signal, dots were made on paper moved by machinery in front of the needles, each of which was furnished with a little tube containing ink. This telegraph was worked through 12 miles and with 3 stations in the circuit: its invention was a great step in the advancement of electro-telegraphing, since it established the fact of the sufficiency of the earth to complete the circuit.

(1065) Professor Morse conceived the idea of his electric telegraph in 1832; it does not appear, however, that he can claim an earlier date than 1837 for its actual construction.* His contrivance included a pen at one end of a wire, which as contact was made or broken, produced an arbitrary alphabet of dots and strokes, which might represent definite characters. An experiment, with a circuit of 10 miles, was tried before several scientific men, well known in the United States and members of Congress; and the result being favourable, a sum of money was voted by the government for a trial on a larger scale. This telegraph being in very general use in America at the present time, a more detailed description of it is necessary:—

On a wooden platform, A B, is fixed a vertical support, C, to which is screwed an electro-magnet E F; on the upper part of the vertical support is a metallic band, G G, the sides of which are pierced horizontally to carry 2 screws tipped with sharp and tempered steel points, between which the lever, L, moves with as little friction as possible. To one of the extremities, D, of the lever is soldered the armature of the electro-magnet; the other end carries one or more steel points, which fit corresponding holes in a steel cylinder, under which the sheet of paper to receive the transmitted message passes, being unwound regularly by clock-work. The galvanic current being established, the armature of the electro-magnet is attracted,

* See Traité de Télégraphe Electrique, par M. l'Abbé Moigno, p. 75, *et seq.*

and at the same moment the points at the opposite end of the lever come into contact with the cylinder, S, and make marks on the paper of greater or less length, according to the interval of time elapsing between the making and breaking of the circuit. To secure the rapidity and certainty of the contacts, a metallic plate, J J, is fixed across the band, G G, carrying 2 screws, the extremities of which serve to regulate the motion of the lever, and to keep it within certain narrow limits just sufficient to secure exactness and regularity. The paper is in one continuous length, and is wound lightly round a wooden cylinder, from which it is afterwards cut into convenient lengths. The operation of the instrument is as

Fig. 410.

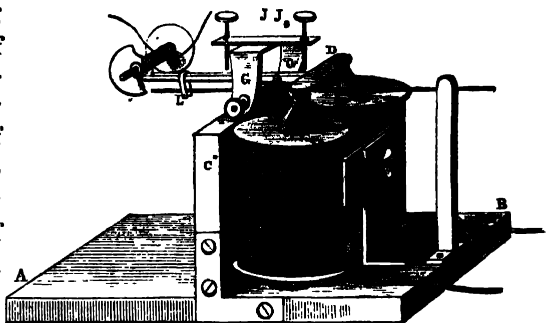


Fig. 411.

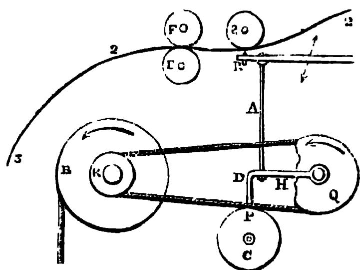


Fig. 412.

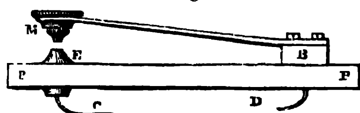
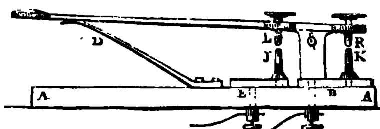


Fig. 413.



follows: Motion is given to the drum or barrel B (Fig. 411) in the direction of the arrow by a weight attached to a cord acting on wheel-work within; the motion is communicated through a series of intermediate wheels to the cylinder E, between which and the cylinder F the paper passes; F is kept in close contact with E by means of a spring; S is the steel cylinder underneath which the paper passes, and R is one of the steel points attached to the lever L (Fig. 410); the pulley Q receives motion in the direction of the arrow from the pulley R in the centre of the barrel B. It carries on its axis a horizontal arm, H, which is immediately under the lever; it is bent at D so as to come into contact with the wooden friction-wheel, C, at the point P. This friction-wheel is fixed under the last screw of the machine, and below the lever. From the lever, L, proceeds a

strip of metal, A, which traverses the arm, H; a screw and nut, I, placed at the extremity of the rod serving to lengthen or shorten it. It must act freely at its point of junction with the lever as well as at its point of junction with the screw H; it also works a hammer, which striking a bell below the platform of the apparatus, warns the operator when a signal is about to be transmitted. Now, as long as the bent arm, H D, is in contact with the friction-wheel, the whole machine is at rest; but when by the action of the electro-magnet on the lever, the rod A is raised, the weight being no longer restrained, gives motion to the barrel B, and the apparatus is put into action, but is again stopped the instant the bent arm touches the friction-wheel. In this way the operator, both near and at a distance, has perfect control over the instrument.

The apparatus or key for opening and shutting the circuit is shown in Fig. 412. A small metallic anvil, E, is secured on a platform, P P; it is in metallic communication underneath with a copper wire, C; M is a metal hammer attached to a spring and soldered to the block, B, also in contact with a copper wire, D. Another and better form of key-apparatus is that shown in Fig. 413, the operation of which will be understood by a single inspection. The hammer, L, is prevented from touching the anvil, J, when the telegraph is at rest, by the spring, D, acting on the lever C; the hammer, R, and the anvil, K, being then in contact: on pressing down the lever, L and J come into contact—the voltaic current passes through the telegraph.

(1066) The alphabet used with this telegraph is constructed by various combinations of the lines and dots in the following manner:—

· —	— · · ·	· · ·	— · ·	·	· — ·	— — ·	· · · ·
A	B	C	D	E	F	G	H
· ·	— · — ·	— · —	———	— —	— ·	· ·	· · · · ·
I	J	K	L	M	N	O	P
· · — ·	· · ·	· · ·	—	· · —	· · · —	· — —	· — · ·
Q	R	S	T	U	V	W	X
· · · ·	· · · ·						
Y	Z						

· — — ·	· · — · ·	· · · — ·	· · · · —	— — —	· · · · · ·	— — · ·	— · · · ·	— · · —	———
1	2	3	4	5	6	7	8	9	0

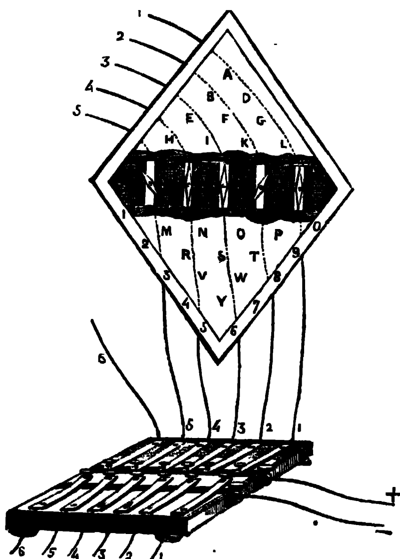
Suppose, now, a message has to be transmitted from one station to another, say from Baltimore to Washington, the key of the first operator is at Baltimore, and his register at Washington; the key of the second operator, on the other hand, is at Washington, and his register at Baltimore. Each has perfect control over his own apparatus, and sets the paper to receive his correspondent's message. The apparatus, wires, and batteries being found to be in good order, the Baltimore correspondent commences his communication, and however

rapidly and suddenly he establishes in his key the contacts between L and J (Fig. 413) the electro-magnet at Washington becomes excited, its armature attracted, the whole machinery of the telegraph brought into full operation, and the communication stamped on the paper in accordance with the above alphabetical characters. It having, however, been found in practice somewhat difficult to regulate the contacts between the hammer and anvil, so as to give full effect to this notation, Morse has substituted for it another code of signals by which a far greater precision is secured.

(1067) Alexander's telegraph, a description of which appeared in the *Mechanics' Magazine* for November, 1837, consisted of 30 coils and 30 magnetic needles. Each needle carried a screen which concealed a letter behind it. On the transmission of the voltaic current through either of the coils (which was effected by pressing down its corresponding key), the needle was moved aside, and the letter on the dial exposed to view; by confining the motion of the needle to one direction only, oscillation was prevented. Mr. Alexander's original instrument was shown at the Great Exhibition of 1851. In Davy's telegraph (1837) the letters or signals were painted on glass, which was illuminated by a lamp placed behind the instrument; as in Alexander's, the letters were exhibited by the deflection of a magnetic needle carrying a screen, which, when the telegraph was at rest, concealed them from view.

(1068) The first patent of Messrs. Cooke and Wheatstone "for improvements in giving signals and sounding alarms at distant places by means of electric currents transmitted through metallic circuits," was sealed on the 12th of June, 1837. The telegraph here patented is shown in Fig. 414, and is thus described by Mr. Wheatstone in his examination before the Parliamentary Committee on Railways:—

Fig. 414.



"Upon a dial are arranged 5 magnetic needles in a vertical position; 20 letters of the alphabet are marked upon the face of the dial, and the various letters are indicated by the mutual convergence of 2 needles

when they are caused to move. These magnetic needles are acted upon by electrical currents passing through coils of wire placed immediately behind them. Each of the coils forms a portion of a communicating wire which may extend to any distance whatever; these wires at their termination are connected with an apparatus, K, which may be called a communicator, because by means of it the signals are communicated. It consists of 5 longitudinal, and 2 transverse metal bars, fixed in a wooden frame; the latter are united to the poles of a voltaic battery, and in the ordinary condition of the instrument, have no metallic communication with the longitudinal bars which are each immediately connected with a different wire of the line; on each of these longitudinal bars, 2 stops are placed, forming together 2 parallel rows. When a stop of the upper row is pressed down, the bar upon which it is placed forms metallic communication with the transverse bar below it, which is connected with one of the poles of the battery; and when one of the stops of the lower row is touched, another of the longitudinal bars forms a metallic communication with the other pole of the voltaic battery; and the current flows through the 2 wires connected with the longitudinal bars to whatever distance they may be extended, passing up one and down the other, provided they be connected together at their opposite extremities, and affecting magnetic needles placed before the coils, which are interposed in the circuit."

The 5 galvanometers or multipliers are numbered 1,1; 2,2; 3,3; 4,4; 5,5; and of the terminal wires 5 are represented as passing out of the side of the telegraph case on the left hand, and the other 5 on the right—they are numbered 1, 2, 3, 4, 5. The wires of the same number as the multiplier are those which belong to it, and are continuous. Thus the wire 1, on the left hand, proceeds from the first coil of multiplier 1, then to the second coil, and then coming off, passes out of the case, and is numbered 1 on the right hand; and so on with the other wires. The letters C, J, Q, U, X, Z, are not represented on the dial. Each needle has two motions, one to the right, and the other to the left. For the designation of any of the letters the deflection of two needles is required, but for the numerals one needle only. The letter intended to be noted by the observer is designated in the operation of the telegraph by the *joint deflection* of two needles pointing by their convergence to the letter. For example—in the figure the needles 1 and 4 cut each other by the lines of their joint deflection at the letter V on the dial, which is the letter intended to be observed at the receiving station. In the same manner any other letter may be selected. Suppose the needle 1 to be vertical as needles 2, 3, and 5, then needle 4 only being deflected points to the numeral 4 as the number intended to be signified.

A second patent for improvements on the needle telegraph was specified by Messrs. Cooke and Wheatstone in October, 1838. It relates principally to a method of enabling two intermediate stations to communicate with each other and with either terminus; and to sounding an alarum by liberating wound-up mechanism by the *angular motion of a magnetic needle.*

(1069) The patent for Messrs. Cooke and Wheatstone's electro-magnetic telegraph bears the date of January 21, 1840. In this apparatus Mr. Wheatstone availed himself of the property possessed by soft iron of immediately acquiring and losing magnetic properties, by the establishment or interruption of a current in a wire covered with silk with which it is surrounded. To transmit all the letters of the alphabet and the figures which may be required in a telegraphic communication, two conducting wires between one station and another, were found sufficient. By means of a commutator, which served to interrupt or establish the circuit at one of the stations, soft iron was magnetized and demagnetized an equal number of times at the other station. The commutator was a wheel turning on its axis, and the circumference of which presented 48 portions alternately conductors, so that for one complete revolution of the wheel the current was 24 times interrupted and re-established; a letter of the alphabet corresponded to each of these 24 alternations; the soft iron at the other station was in like manner magnetized and demagnetized 24 times. This alternate state of the magnetization and non-magnetization of the soft iron, gave an oscillating motion to a small appendix of soft iron, which communicated a similar motion to a wheel by which each of the twenty-four letters of the alphabet engraved on the wheel were brought successively before the observer. Care was required to insure an agreement between the letters corresponding to the alternations of the commutator, and those produced by the alternate movement effected by the magnetization and demagnetization of the electro-magnet. Tho following was the method of working this telegraph: Suppose the commutator placed at A, and the letter A brought to the observer by the electro-magnet (at each station they agree to arrange the apparatus that the starting point shall be the same), we wish to transmit the letter D; the commutator must be moved onwards 3 alternations; B, C, and D, have been successively introduced at the other station, and so on for each of the letters. A large bell which was struck by a piece of iron attracted by the electro-magnet at the moment when the circuit was re-established, served to give the signal. It is evident that in order that the transmission be reciprocal, there must be

a double set of apparatus, so that each station may possess those necessary to transmit, and those necessary to receive the communication.

(1070) An addition to this was afterwards made and patented by Mr. Wheatstone, by which the letters were *printed* instead of their being merely presented to the eye. The following are the means by which this is effected: For the paper disc of the telegraph, on the circumference of which the letters are printed, a thin disc of brass is substituted, cut from the circumference to the centre, so as to form 24 springs, on the extremities of which types or punches are fixed; this type-wheel is brought into any desired position just as the paper disc is. The additional part consists of a mechanism, which, acted upon by an electro-magnet, occasions a hammer to strike the punch, brought opposite to it, against a cylinder, round which are rolled alternately several sheets of thin white paper, and of the blackened paper used in the manifold writing apparatus; by this means, without presenting any resistance to the type-wheel, several distinct copies of the message transmitted are obtained.

The great practical difficulty with this telegraph was that of insuring the synchronism of the movements of discs at the different stations,

Fig. 415.

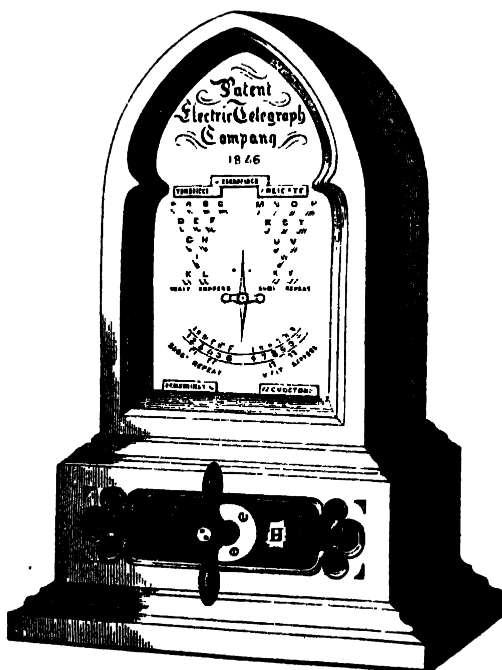
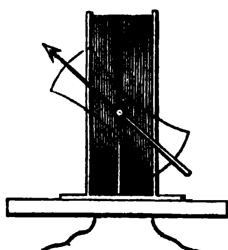


Fig. 416.



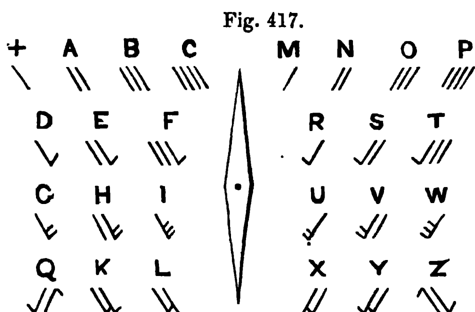
or if they did not move precisely together, then when B was visible at one station, A would be in view at another, and thus all would go wrong. It has, therefore, been entirely abandoned for other and better plans.

(1071) Messrs. Wheatstone and

Cooke's single-needle telegraph, patented May 6th, 1845, is shown in Fig. 415. The essential part of the instrument is composed of a single multiplier, with an indicator fixed vertically on a horizontal axis, and moving in front of a dial plate. This indicator may be either a light strip of wood, or a magnetic needle; if the latter, its poles must be in a reversed position to those of the needle within the bobbin. When the voltaic current is sent through the coil the needle is deflected to the right or to the left, according to the direction in which the current passes. The alphabet is situated both on the right and the left hand side of the needle; some letters require 4 movements of the needle, but the last motion which completes the indication of a letter situated on the right hand side is always a movement to the right; in like manner the last motion which completes the indication of a letter on the left side is always a movement to the left; for example—the letter W is indicated by 4 motions of the needle, 3 to the left and 1 to the right; the letter L also is indicated by 4 motions, first to the right, then to the left, then again to the right, and finally to the left.

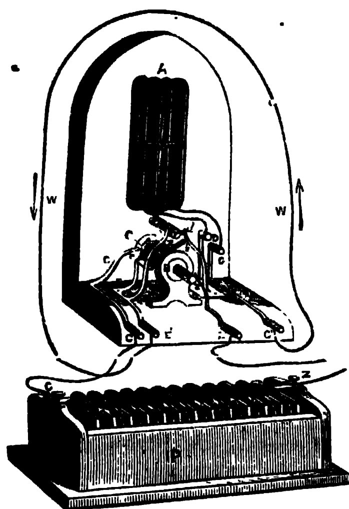
(1072) The code of signals adopted is shown in the following diagram; and bearing in mind that the deflections of the symbols for each letter commence in the direction of the short marks and end with the long ones, it will be seen that the deflections of a single needle may be made to denote all the letters of the alphabet.

Fig. 417.



The numerals are inscribed on the dial underneath the needle, and are indicated by the movements of its lower half; for example—the figure 4 is designated by the motion of the lower extremity once to the right and once to the left; the figure 9 by a movement once to the left and once to the right, and so on. The internal mechanism of the telegraph is exhibited in Fig. 418. B A is the bobbin, in the interior of which is placed either a single magnetic needle, in the form of a rhomboid, $1\frac{1}{4}$ inch long by $\frac{7}{8}$ths of an inch broad; or which Mr. Walker found to be still better, several highly magnetized short needles, firmly secured on either or both sides of a very thin ivory disc. The exterior or index needle is about 3 inches long. The frame of the coil, B, is made of copper,

Fig. 418.

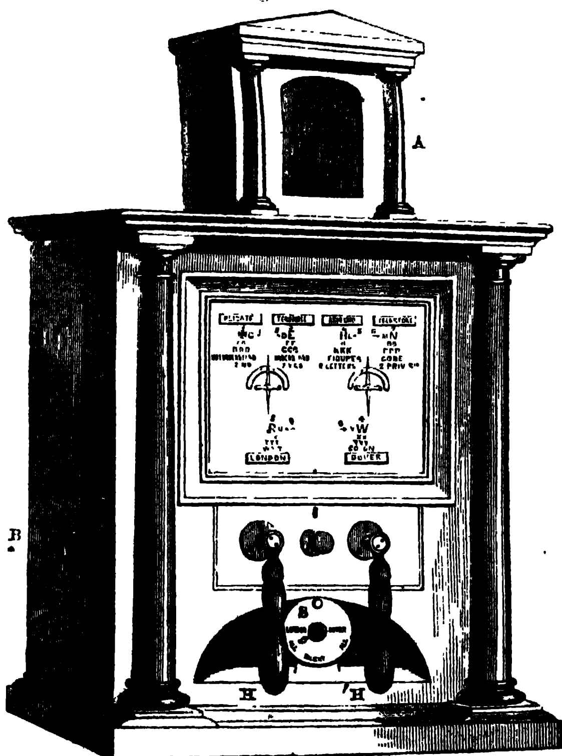


wood, or ivory; it is screwed to a plate of varnished copper against the side of the telegraph case. The copper wire surrounding the bobbin A is about $\frac{1}{100}$th of an inch in diameter, and is well covered with cotton; one end of the wire from the right hand bobbin is in contact with the screw G, which, by means of a metallic strap, is connected with the screw G′ secured on the base of the apparatus; the other end of the wire on the left hand bobbin is in contact with another screw, D, supported by a strip of brass which is fixed to the base; from this brass plate there rises an upright stiff steel spring *d*, which presses strongly against a point attached to an insulated brass rod, *r*, screwed against the side of the case; on the opposite side of this rod is another point against which a second stiff steel spring, *d′*, presses; this spring is attached to a brass plate, E, terminated by a binding screw E′; E′, therefore, is the screw terminal of the wire from the left hand coil. If G′ and E′ be now connected by a wire, W, the current will flow from G′ through G into the right hand coil, out from the left hand coil to D, thence through *d r d′* to E, and from the terminal screw E′, round the wire circuit, back to G′; and if the wire from G′ proceed *up* a line of railway, and the wire from E′ *down* the line, the circuit being complete throughout, the needle in the bobbin, A, will be deflected by a current proceeding from any station on the line, and thus signals will be communicated. Battery contact is broken and the direction of the current reversed by the action of the springs *d d′* in the following manner:—

B is a box-wood drum, moveable by a handle seen at H, in the front of the base of Fig. 415. Round either end of this drum are fixed the brass caps C and Z; the caps do not touch each other, a disc of box-wood being between them. Into these caps are screwed the steel projecting pieces C′Z′, which become the poles of the battery, the Z′ being connected with the zinc end, and C′ with the copper, thus: a wire, C, from the copper end of the battery conveys the current, C′C′, and a wire from the zinc end along Z, to a steel spring, which touches *z*, the continuation of the Z end of the box-wood cylinder. Now on moving the drum, by turning the handle, H,

Fig. 415, the steel spring *d* will be raised from its corresponding point on *r*; the circuit will thus become broken, but by continuing the motion of the drum, the wire C will come into contact with the spring below it, and thus there will be a battery pole at either end of the drum, and signals will thus be made on the dial, and on all the instruments connected with it. The connexions are made in such a manner, that when the handle is turned to the right the needle moves to the right. The exterior, or indicating needle is always placed with its N. pole upwards; that within the coil with its N. pole downwards; so that, in accordance with Oersted's fundamental law, looking at the face of the instrument, if we see the upper part of the needle moving towards the right, the spectator may be sure that the current is ascending in that half of the wire which is nearest to him.

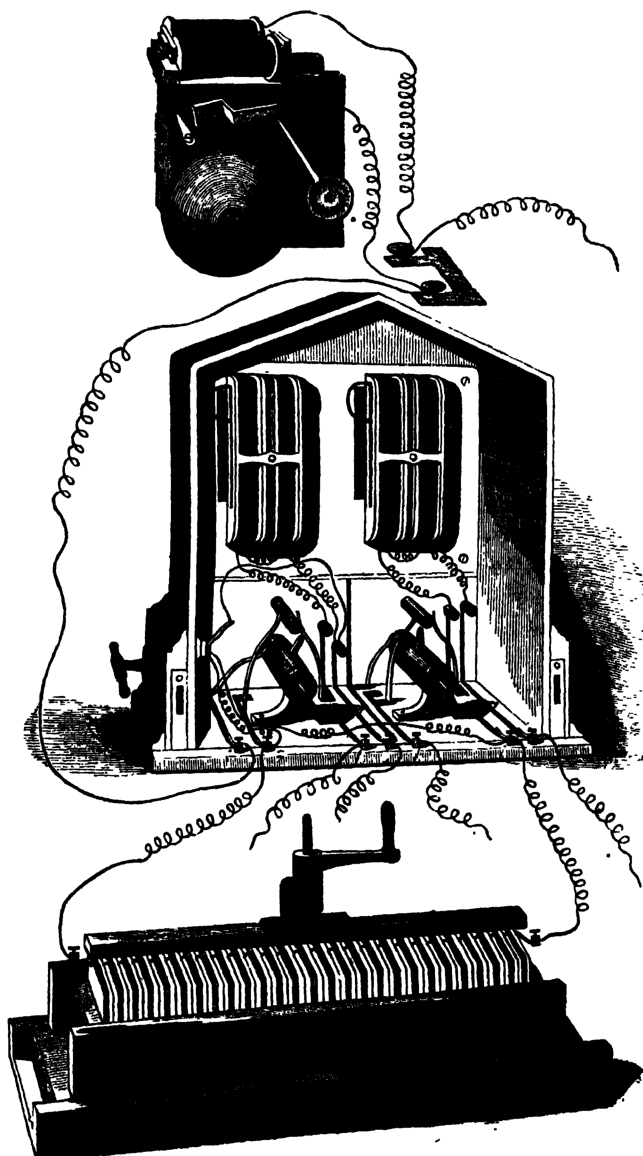
Fig 416.



(1073) Messrs. Cooke and Wheatstone's double-needle telegraph, now in general use for railway service in this country, is shown in Figs.

419 and 420. On the top of the case is the alarum, A, which is worked by the handle, B. H H′ are the handles by which the two needles are manipulated, and S is the "silent apparatus." The internal mechanism is precisely similar to that of the single-needle apparatus. The

Fig. 444.



letters of the alphabet are ranged from left to right, as in the ordinary mode of writing, in several lines above and below the points of the needles, the first series, from A to P, being above, and the second series, from R to Y, below. Each letter is indicated by one, two, or three movements. The following is the complete vocabulary and mode of correspondence:—

A. Two movements towards the left, by the left needle.

B. Three movements towards the left, by the left needle.

C, and the Fig. 1. Two movements of the left needle, the first to the left, and the second to the right.

D, and the Fig. 2. Two movements of the left needle, the first to the right, and the second to the left.

E, and the Fig. 3. One movement of the left needle to the right.

F. Two movements of the left needle to the right.

G. Three movements of the left needle to the right.

H. and the Fig. 4. One movement to the left of the right hand needle.

I. Two movements to the left of the right needle.

J is omitted, and replaced by G.

K. Three movements of the right needle to the left.

L, and the Fig. 5. Two movements of the right hand needle, the first to the right, the second to the left.

M, and the Fig. 6. Two movements of the right needle, the first to the left, the second to the right.

N, and the Fig. 7. One movement of the right needle towards the right.

O. Two movements of the right needle to the right.

P. Three movements of the right needle to the right.

Q is omitted, and K substituted for it.

R, and the Fig. 8. A single movement of both needles towards the left.

S. Two movements of both needles towards the right.

T. Three movements of both needles towards the left.

U, and the Fig. 9. Two movements of both needles, the first towards the right, the second towards the left.

V and 0. Two movements of both needles, the first to the left, the second to the right.

W. One movement of both needles towards the right.

X. Two movements of both needles towards the right.

Y. Three movements of both needles towards the right.

Z is omitted, and replaced by S.

The sign +, indicating the termination of a word, is designated by a single movement of the left needle towards the left; the same signal is given when the receiver does not understand his correspondent's message. The exhibition of the letter E signifies that he *does* understand, and to denote the word *yes*. The signal for E is repeated twice, *i. e.*, two movements of the left needle towards the right are made.

(1074) The words "*wait*," "*go on*," seen on the right and left side of the bottom of the dial plate are of great importance. Suppose, for example, the London clerk wishes to communicate with his correspondent at Dover, and that the latter is at the time engaged, he immediately signals the letter R, thereby intimating that he is not prepared to receive the London message; when he is at liberty, he directs his needles towards W, which means "go on," and the correspondence begins. It is also absolutely necessary to have a method whereby one station may signify to any individual station on the line that a message is proposed to be sent to it. Suppose, for example, that London wishes to communicate with Tonbridge; on the dial plate of Fig. 419 will be seen the names of the six stations of one of the groups on the South Eastern Railway, *viz.*, Reigate, Tonbridge, Ashford, Folkstone, London, and Dover; each of these stations is represented by a letter. Thus, London is designated by R, Tonbridge by E, Dover by W, and so on. The London correspondent signals E, and at the same time rings the bell at the station at Tonbridge; the Tonbridge clerk immediately returns the ring at London, thereby intimating that he is at his post. London now signals R, by which Tonbridge knows that it is London that wishes to communicate with him; he returns the signal R; London again rings the bell, and the correspondence commences,—Tonbridge signalling the letter E after every word if he understands, or the cross + if he does not. The message being finished, London deflects his left hand needle twice to the left; Tonbridge returns the signal, if he has no reply to make, and proceeds to transmit the message to its destination.

The numerals are indicated by certain letters; the letter H, followed by a cross +, intimating that figures and not letters are about to be shown. The letter W interposed between certain figures serves to group them: thus the letters HE W N might mean £43 7*s.*, or 43 feet 7 inches, &c. Special signals are also devised for special purposes.

(1075) The mechanism of the alarum used on the telegraphic line of the South-Eastern Railway Station is shown in Fig. 421.

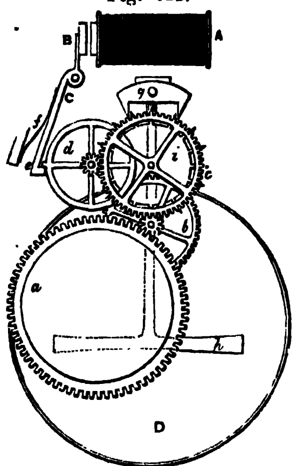


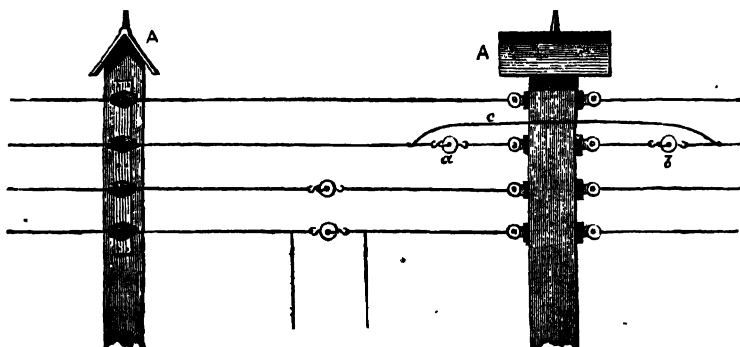
Fig. 421.

A is an electro-magnet; B, an armature of soft iron, which is attracted as often, and as long as, the voltaic current circulates round its bobbin. This armature is prevented from coming into actual contact with the pole of the electro-magnet by means of two little copper studs, tipped with ivory, inserted in its face; this is necessary, because as soft iron does not lose the whole of its Magnetism when the battery circuit is broken, permanent adhesion would otherwise ensue. The armature is mounted on the short arm of a lever, C, carrying at the end of the other arm a short projecting piece *e*, which, catching in a stop in the circumference of the wheel *d*, prevents it from moving. The armature is brought back to its normal position, when the attraction ceases by the small spring *f*, which presses against the long arm of the lever. Of the clock-work contained in the barrel, only the principal pieces are shown in the figure; the cog wheel *b* is connected by a pinion with the cog-wheel *a*, which works *i*, and this again gives motion to *d*, which carries the stop. The anchor escapement *g* works on the wheel *i*, and on the axis of the same wheel is placed the double-headed hammer, *h*. On completing the battery circuit, the armature, B, is attracted by the electro-magnet, the long arm of the lever, C, moves to the left, and the wheel *d*, being then set at liberty, the mainspring in the barrel, which is kept constantly wound up, sets it in motion, and the hammer is instantly put into rapid vibration, striking alternately the opposite sides of the bell, D; the ringing is kept up as long as the circuit is closed, but the moment it is broken the armature is detached by the spring *f*, and the catch is again pressed into its place on the wheel *d*. It is not the voltaic current that rings the bell, but the mainspring in the barrel; all that the Electricity does is to disengage the catch; and there is no greater difficulty, therefore, in ringing a large bell than a small one. It is easy to see that this principle may be modified in a variety of ways.

(1076) The batteries used to work our English telegraphs are composed of amalgamated zinc and copper plates, 4½ inches long by 3½ inches wide, the zinc being $\frac{3}{16}$ths of an inch thick. The plates are cemented water-tight on to stout teak-wood or oak troughs, each trough being from 15 to 30 inches long, and 5½ inches wide, and divided into

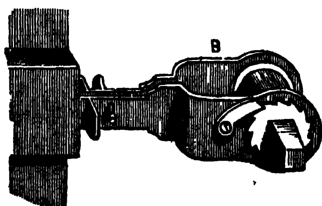
12 or 24 cells by partitions of slate. The plates connected together by copper slips, are placed across the slate partitions, and the cells are filled to within an inch of the top with siliceous sand, which is then saturated with a solution of 1 part of oil of vitriol in 15 parts of water. The numbers of cells used varies according to the distance between the stations: for short groups of 10 or 15 miles, 24 cells are employed, for distances from 40 to 60 miles double that number. The telegraphs on the South Eastern Railway of 180 miles and 47 stations are worked with 2,200 pairs of plates, and the whole telegraph system in the United Kingdom employs about 20,000 pairs. (Walker's "Electric Telegraph Manipulation," p. 9.) According to Mr. Walker's experience, new batteries, when carefully put together, will, with care, do duty for six or eight months, when the work is not very heavy; and by washing the sand out with a flow of water, and refilling them, they frequently remain on duty ten or twelve months without being re-amalgamated. In America, for the registering telegraphs, Grove's battery is mostly in use, 30 cells of which are required for a distance of 150 miles. They require cleaning and replenishing about once a fortnight.

Fig. 422.



(1077) The modes of sustaining and insulating telegraphic wires adopted nearly universally in England are represented in Figs. 422 and 423. Wooden posts, from 15 to 30 feet high, are fixed firmly in the ground, at the rate of about 30 a mile; the upper part of each post is 5 or 6 inches square; it carries a wooden arm, which is separated from the post by discs or rings of brown delf-ware. The arm is secured to the post by an iron bolt and screw. On the face of the wooden arm, 4 hollow double earthenware or glass cones are fas-

Fig. 423.



tened by collars of iron; through these the wires pass, and are thus effectually insulated. A similar system of wires passes on the opposite side of the post, and each post is provided with a small roof of earthenware or slate, on the top of which is a metallic point connected with the earth as a preservative against the effects of lightning. The contrivance for tightening the wires is seen at B. The posts on which this apparatus is placed are much stouter than the ordinary sustaining posts, and they are fixed at intervals of $\frac{1}{4}$th of a mile apart. To the upper part of the post are attached as many iron screws as there are telegraph wires, and each screw carries a winder, consisting of a grooved drum with a wheel and ratchet attached; the ends of the winder are insulated from the post by discs of earthenware; *a* and *b* are two earthenware pulleys, or *shackles*, each furnished with two hooks insulated from each other. The winding post is thus seen to be out of the circuit, but the metallic continuity of the telegraph wire is secured by a thin wire, *c*, soldered to the outside of each shackle. The telegraph wire is of iron, about $\frac{1}{6}$th of an inch in diameter: it is protected against the corroding action of atmospheric air and moisture by being passed through a bath of melted zinc, or *galvanized*, as it is called; zinc being more positive than iron, combines first with oxygen; the wire thus becomes coated with a thin layer of oxide of zinc, which acts as a coat of paint and effectually preserves the iron. In the neighbourhood of large towns, where great quantities of coal are daily burned, the sulphurous vapours arising from such fuel and passing over the oxide of zinc covering convert it into sulphate of zinc, which being soluble in water, is immediately melted by the rain and drops off. The wire thus deprived of its insoluble covering soon corrodes. Mr. Highton mentions ("Electric Telegraph," p. 117) that he has seen galvanized iron wires reduced in this way in less than two years from the diameter of $\frac{1}{8}$th of an inch to that of a common sewing needle; and he suggests that in the neighbourhood of large towns the wires should either be painted and varnished, or entirely cased in gutta percha.

(1078) The insulator employed on the "Morse" line from New York to Washington, is simply a glass knob with 2 rings, between which the wire is wrapped. It is said to be very imperfect (Turnbull on the "Electro-magnetic Telegraph," p. 176), the wire losing its insulation almost entirely in wet weather, and the instruments working with difficulty upon even the slightest shower. It has been found also, that with this form of insulator, the atmospheric Electricity cracks the glass in two pieces, just as if it had been cut with a diamond. In the "House" line of telegraph (American) the glass cap, which is

covered with lac varnish, is screwed into a bell-shaped iron cap, which is filled with much care to the top of the post, and well painted and varnished, the telegraph wire is fastened to the top of the cap by projecting iron points. This plan, though decidedly superior to Morse's, is objectionable on the score of expense, and very inferior to the method adopted in England. In Germany, the wires are insulated by passing through porcelain caps, in the shape of a reversed cup, placed on the summit of the posts, which are thus covered with roofs. It is said to be very perfect. The posts in France are from 20 to 30 feet long, and are driven into the ground to a depth of from 30 to 60 inches, the buried parts being preserved by injection with sulphate of copper. The insulators, which are either bell-shaped or double oblique cones, are, as in England, fixed to the side of the post by screws, and sealed with sulphur in the interior; the conducting wire passes through a ring support fixed in the interior of the cone, so that the wire only passes on a point sheltered by the mass of the support.

When the conducting wires have to pass underground, they are usually made of copper, and are either covered with gutta percha or with cotton saturated with tar, and collected in leaden pipes in groups of three or four; the leaden pipes are covered with a pitched cord, and the whole placed in an iron pipe.

(1079) When the wires have to pass under water, as in the submarine telegraphs, great care is required for their insulation and protection. The first wires for the submarine telegraph between England and France were sunk in the British Channel, in August, 1850. The wire was 30 miles long, simply covered with gutta percha, and sunk to the bottom of the sea by leaden weights; it soon, however, became useless, being cut to pieces by attrition against the rocks. In the September of the following year, a submarine cable was constructed by Messrs. Newall and Co., and on the 18th of October, an electric communication was established between Dover and Calais, a distance of 21 miles. The plan adopted in the manufacture of this cable was as follows (Highton on the "Electric Telegraph"): A copper wire, No. 16, was first carefully covered with gutta percha; upon this a second covering was laid—the wire was thus thoroughly insulated. Four of these were then bound together with spun-yarn and hemp saturated with tar. This bundle of insulated wires with its hempen covering was then surrounded by 10 galvanized iron wires, each wire being $\frac{6}{10}$ths of an inch in diameter. The insulated wires thus formed the core of a large continuous wire rope (Fig. 424), which was wound into a coil 30 feet in diameter. It was 24 miles long, and weighed 180 tons.

Fig. 424.



(1080) The "paying out" of this enormous cable commenced Sept. 25th, 1851. Steam tugs were placed by the Admiralty at the service of the Company. The Blazer, on which the cable was shipped, was towed from Dover to the South Foreland, and one end of the rope conveyed on to the English shore; after this, the vessel was towed in the direction of Cape Grinez. The distance between the two coasts is 20 miles, and though to allow for undulations and sinuosities 24 miles of cable had been constructed, the end of the rope was found to fall short of its destination by half a mile; another mile of cable was made, and spliced to the end of the first; and on the 18th of October, the communication was found to be perfect. The cost of this cable is said to have been £20,000, and the expenses to the Company to have been no less than £75,000. The success of this experiment stimulated Messrs. Newall and Co. to attempt a still greater enterprise, *viz.*, that of connecting telegraphically England and Ireland, by extending a submarine cable between Holyhead on the Welsh, and Howth on the Irish coast. This they effected in June, 1852, but from some unascertained cause (probably from its being too light, the cable enclosing only a *single* wire, and weighing only *one ton* a mile—the Dover and Calais cable weighing seven tons), after working well for three days, it became imperfect, and a great portion has been taken up. Nothing daunted by this failure, Messrs. Newall and Co. constructed a cable measuring seventy *miles* in one unbroken length, and with it, on the 6th of May, 1853, the first electric telegraphic communication was established between Belgium and England. This cable contains 6 wires, insulated by gutta percha, and laid into a rope with prepared spun yarn; it is covered with 12 thick iron wires, of a united strength equal to a strain of 40 to 50 tons—more than the proof strain of the chain cable of a first-rate man-of-war (Lardner on the "Electric Telegraph," p. 157). It weighed 7 tons a mile, its total weight being 500 tons; its cost was £37,000.* The great success which has hitherto attended submarine telegraphing has given rise to a project for the deposition of an

* For a graphic illustration of the manner in which this enormous cable was coiled in the hold of the vessel; also for the way in which it was deposited, see Illustrated London News, May 14, 1853.

electric cable across the Atlantic, so as to put the Old World into instantaneous communication with the new, a distance (between the nearest point of British America and the west coast of Ireland) of about 1,600 miles. Whether the curious phenomenon of the arrest of the Electricity supplied by voltaic battery, and the charging of the submerged or buried wire elsewhere described (316), would interfere with the realization of this project is a question which must be left for time and further experience to determine. It should, however, be mentioned that the Magneto-electric Telegraph Company, who have nearly 900 miles of underground wire in operation, report that they sometimes pass their signals, without any difficulty, through 500 miles of underground wire without any break or delay in the circuit. (Lardner on the "Electric Telegraph," p. 172.)

(1081) *The Earth Circuit.*—It had long ago been shown by Watson and others (10) that a Leyden phial could be discharged through a circuit, one half of which consisted of moist earth. It appears that Steinheil was the first to employ the earth to act the part of a conducting wire in an electro-telegraphic circuit. The two extremities of the wire of his telegraph, constructed at Munich in 1837, were attached to two copper plates, which were buried in the earth. He attributed the transmission of the current to the direct conductibility of the earth. It was proved on a larger scale in 1841, by Messrs. Cooke and Wheatstone, by experiments on the Blackwall Railway, that the earth may be employed successfully to replace one half of the conducting wire, or for the *return* circuit. In fact, they state that so excellent a conductor is the earth, and so little resistance does it offer to the transmission of Electricity, that the same pile will work a much greater distance with a circuit half wire and half earth than when altogether wire.

(1082) Whilst prosecuting some experiments with an electro-magnetic sounding apparatus, in the year 1841, Mr. Bain found that if the conducting wires were not perfectly insulated from the water in which they were immersed, the attractive power of the electro-magnet did not entirely cease when the circuit was broken. With a view of ascertaining the true cause of the phenomenon, Mr. Bain, in conjunction with Lieutenant Wright, made a series of experiments on the Serpentine river in Hyde Park, and after verifying their former observations relative to the remnant of power in the electro-magnet when contact with the battery was broken, the electro-magnet being on one side of the river, and the battery on the other, the wires passing *through* the river; and after making other experiments, in which the water and the moist earth formed part of the circuit, and wire the remainder, it occurred to Mr. Bain, that if a

positive metal were attached to one end of the conducting wire, and a negative metal to the other, and if the two metals were then placed in water, or buried in the moist earth while the connecting wire was properly insulated, a current might be generated. This was found to be the case, for when a large surface of copper was placed within Kensington Gardens at the one end of the river, and within Hyde Park at the other end a similar surface of zinc, and the metals connected by a wire, in the circuit of which was a galvanometer, a current of considerable intensity was found to be passing. The experiment was next tried on a more extended plan; a surface of zinc was buried in the moist earth of Hyde Park, and at rather more than a *mile distant*, a surface of copper was buried, and the metals were connected by a wire suspended on the railings; when the plates were large, Mr. Bain not only obtained the usual electro-magnetic effects in an enhanced degree, but also succeeded in the performance of electrotype operations; for in the course of a few minutes he coated a half-crown with copper. Subsequent experiments showed that if the metals are thus buried, and connecting wires are employed, electrotype depositions may be effected, and electro-magnetic apparatus worked for a great length of time.

(1083) Signor Ch. Matteucci made in the year 1844, numerous experiments on the conductibility of the earth for the electric current, (*Comptes Rendus*, June 3rd, 1844). He made the current from a single Bunsen's element (371) circulate in a copper wire, 9,281 feet long, and through a bed of earth of the same length; and he found the diminution which occurred in the intensity of the current to be such, that the resistance of the bed of earth must not only be regarded as nothing, but that further, the resistance of the copper wire entering into the mixed circuit must be considered as less than that presented by the same wire when it enters *alone* into the circuit. Experiments were made to ascertain whether this extraordinary fact was due to the passing of a voltaic current between the buried plates, but on closing the circuit with the earth and the wire *without* the pile, a deviation not exceeding 1° was obtained, and this shortly disappeared. It then occurred to Matteucci, that an explanation might possibly be given by having recourse to a current derived from Ampère's terrestrial currents. The battery current in the first experiments passed along the wire from E. to W.; he now reversed the current, causing it to pass from W. to E.; the deviation of the galvanometer, however, remained the same, as was also the case when the current was caused to pass from N. to S. or from S. to N. These experiments were afterwards repeated on greater lengths at Milan, and their results confirmed Matteucci in the conclusion to which he

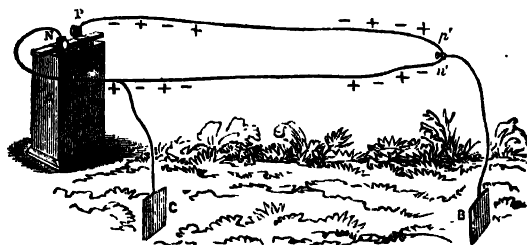
had previously arrived, viz., that when a current is transmitted by a circuit composed in parts of a long copper wire and of a long bed of earth, the diminution suffered by this current from the resistance of this mixed circuit, is less than that which it would have suffered by the resistance of the copper wire alone. Matteucci regards the earth as all other conducting bodies, its great volume making up for its inferior conductibility; he quotes the following experiment (*Comptes Rendus*, Jan. 12th, 1846), as conclusive against the hypothesis that the two electric charges liberated at the extremities of the pile always find means of diffusing themselves into the earth, which being a universal reservoir, succeeds in neutralizing their charges with its natural fluid, decomposed by the free fluid of the pile.

Experiment: The circuit of a pile of 10 Bunsen's elements, was established by plunging the two poles in two wells 160 metres apart; a galvanometer being in the circuit to ensure the passage of the current. In this interval were two other wells almost in a straight line with the two extreme wells. The distance between these two wells was 30 metres; they were distant from the two extreme wells, one, 80 metres, the other, 50. The extremities of a good long wire galvanometer were plunged into the two intermediate wells: the current was then passed in the long circuit, when a deviation of 35° or 40° was instantly obtained; on reversing the direction of the current in the long circuit, that of the *derived* current was likewise inverted. This, remarks Matteucci, is precisely what ought to be the case, if we admit that the electric current is transmitted in the ordinary manner, whilst it cannot be conceived under the other hypothesis.

(1084) The improbability of the earth's acting as a mere conductor in these cases, is strikingly shown by the following experiments made by M. Breguet, on the telegraph line between Paris and Rouen (Moigno's "Télégraphe Electrique," p. 259,) one of the poles of the Paris battery was soldered to a large metal plate, which was plunged into a well, the other pole communicated with the line wire to Rouen, and was there fastened to a similar metal plate, which was also plunged into a well; the circuit was thus half earth and half metal, or the circuit could be made metallic throughout. Similar arrangements were made at Rouen. Two zinc galvanometers, in every respect similar and working together with great uniformity, were employed to measure the electric forces at the two stations. The mean of twenty-eight experiments showed that when the current was half metal and half earth, the intensity was *twice as great* as when it was metallic throughout, that is, a circuit of 40 miles earth and 40 miles wire presented the same resistance as a circuit of 40 miles wire; the earth, in fact, offering no resistance at all. The intensity at Paris, of the current

transmitted through a copper wire to Rouen, and from Rouen back to Paris, through the earth was 56° 8′; that of a current sent and returned through a copper wire 29° 1′, or nearly one-half. At Rouen, the mean relative intensities were the same being 35° 5′ and 17° 8′. Moigno and Gauss both regard the earth as a reservoir or drain in which the positive Electricity on the one side, and the negative on the other are absorbed and lost. Thus let A (Fig. 425) represent the cell of a voltaic battery, P and N being its two poles united by a metallic conductor; according to the theory of Ampère, the Electricity set free at the positive pole, meeting with a resistance in the conducting wire, decomposes the neutral Electricity of the nearest molecule, attracting the negative and repelling the positive; the positive fluid of the first attracts the negative Electricity of the second, and repels its positive; this again acts on the neutral Electricity of the third, and so on, the decomposition proceeding step by step; the positive Electricity of the last molecule, p, being neutralized by the negative Electricity emanating from the N. pole of the battery. Immediately succeeding the first series of decompositions is a second series of recompositions, the last negative molecule, $-n$ being separated from its associated positive molecule, and thus becoming free, now combines with the positive molecule which precedes it, the negative molecule of which combines with the positive immediately behind it, and so on step by step. Suppose now the metallic circuit to be broken, between two free molecules, $+ p'$ on the positive side, $+ - n'$ on the negative, and that a communication be made with the earth through the metallic plates, B and C. The positive molecule will be brought into contact with an enormous reservoir, into which it will flow without meeting with any resistance; it will not, therefore, exercise any decomposing action, being in fact simply absorbed. The preceding negative molecule being again set free, will immediately combine with the contiguous positive molecule, and the same will happen at the negative end of the battery. A *double* series of decompositions and recompositions thus takes place, and this only in one-half of the circuit; the resistance is consequently reduced one-half, that is, the intensity of the current is doubled.

Fig. 425.



(1085) It must be admitted that there is some difficulty in this theory of the "drinking up" of Electricity by the earth, and that the

question is still open to investigation; but whatever may be the true explanation of this remarkable function of the earth, its discovery has been a great boon to electro-telegraphy, and the fact that the earth absolutely offers no resistance whatever to the circulation of the electrical force, is taken due advantage of on all telegraphic lines. "Of all the miracles of science," observes Lardner ("The Electric Telegraph," p. 123), "surely this is the most marvellous. A stream of electric fluid has its source in the cellars of the Central Electric Telegraph Office, Lothbury, London; it flows under the streets of the great metropolis; and, passing on wires suspended over a zigzag series of railways, reaches Edinburgh, where it dips into the earth and diffuses itself upon the buried plate. From that it takes flight through the crust of the earth and *finds its own way* back to the cellars at Lothbury!" But this is not all; though offering less resistance to the circulation of the electrical force than the *best* of all conductors, it at the same time acts as the most perfect insulator. Of this the following striking illustration is given by Mr. Walker ("Electric Telegraph Manipulation," p. 35): "Ten wires enter the London office, each going to one side of the galvanometer; the other sides of the galvanometers are connected respectively by ten wires with a long slip of brass, which brass is connected with the water-pipes; so that, in point of fact, the wires, notwithstanding all our care and cost to keep them insulated from each other throughout their course along the railway,* are actually *one and all clustered together*, and connected into one common bundle, as soon as they have passed the galvanometer. Notwithstanding this *oneness* of the wires, provided all is clear along the line, a current can be sent along any one of the ten, without any portion being distributed among the other nine. Take the case of two wires only as an example. They

* The difficulty of obtaining perfect insulation of the wires is one of the greatest impediments to the establishment of telegraphic communication. The difficulty is increased when wires forming short circuits are placed in close proximity to those of long circuits. Under these circumstances, if the wires are not protected by an insulating coating, there is frequently in a damp state of the atmosphere, an escape of Electricity from the long wire to the short one, and a consequent diversion of the Electricity from its intended course; for although the low intensity of voltaic Electricity may in experiments on a limited scale effectually prevent it from passing through a thin stratum of moist air, it must be remembered that each iron wire from London to Liverpool exposes a surface of not less than 45,000 square feet, and between several surfaces of that extent only 6 inches apart, a large quantity of Electricity may be transferred and lost. The escape of Electricity from telegraph wires, in the manner now alluded to, was first brought under the notice of telegraphic engineers by Mr. Bakewell. ("Bakewell on Electric Science," p. 157.)

are united, and are joined to the earth wire before they enter the London instrument. They are kept carefully apart from London to Dover, but after passing the Dover instrument, they are again united, and are joined to the earth wire, so that they form a continuous loop; and yet the current intended for one wire always takes the earth as the *return half* of the circuit, and no part of it finds its way into the companion wire. But if by any accident the earth wire is divided, the case is widely altered, and the current tells its own tale by its reverse action on the galvanometer, for it now accepts the companion wire, which before it entirely rejected."

(1086) The necessity of paying the utmost attention to the insulation of the line wire, involves the introduction of a difficulty of another kind, and which has to be carefully guarded against; that, viz., arising from the action of atmospheric Electricity, both induced, and in the form of direct strokes of lightning. "More damage," observes Mr. Highton ("The Electric Telegraph," p. 11), "is often done to the telegraph in a second by a single thunder storm, than by all the mischievous acts of malicious persons in a whole year." Posts are split in pieces, coils of wire are fused, needles are demagnetized, and permanent Magnetism given to soft iron electro-magnets. In the year 1846, the electric telegraph on the St. Germains Railway was visited by an attack of atmospheric Electricity, the following account of which was communicated by M. Breguet to M. Arago ("Year-Book of Facts," 1848): "About five o'clock in the afternoon, during a heavy fall of rain, the bells of the electric telegraph at Le Vesitret began to ring, which led the attendant to suppose that he was about to receive a communication. Several letters then made their appearance, but finding they conveyed no meaning, he was about to make the signal "*Not understood*," when suddenly he heard an explosion, similar to a loud pistol-shot, and at the same time a vivid flash of light was seen to run along the conductors placed against the sides of the shed. The conductors were broken into fragments, their edges being fused. The wires of several electro-magnets were also broken, and the attendant who was holding the handle which moves the needle sustained all over the body a violent concussion, and several workmen standing about him also experienced severe shocks." At the other end of the line, at the Paris station, nothing was broken, and nothing remarkable occurred, excepting that several of the bells were heard to ring. At the Oundle station of the London and North-Western Railway considerable mischief was done in 1846, several of the coils being burst open, and the wires fused; and at the Chilham station, on the South-Eastern Railway, a flash of lightning destroyed, in August,

1849, the wire of the bell coil and both the galvanometer coils. In India, which is occasionally visited with storms of lightning such as we never witness in this country, the damage done is often much more severe; and in America, the disastrous consequences resulting from the same cause, soon after the establishment of the first line of telegraph by Morse, in 1844, rendered it imperatively necessary to devise some means for the protection of the operators and instruments.

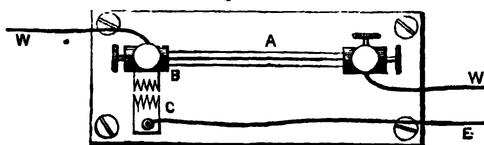
(1087) Numerous forms of lightning conductors have been invented and adopted. Actual lightning flashes are warded off by the points visible above the posts (Fig. 421), which are connected with the earth by a wire. Highton's plan, which he states to be so effectual that since its adoption not a coil has been injured, is very simple. He surrounds the wire for 6 or 8 inches before it enters a telegraph instrument with bibulous or blotting paper, and passes it through a deal box lined with tin plate in connexion with the earth; the box is then filled with iron filings. All high tension Electricity collected by the wires will at once dart through the air in the bibulous paper to the myriads of points in the iron filings, which carry it safely to the earth. Walker's "protector" consists of a small hollow metal cylinder connected with the earth. The line wire in its passage from the railway to the telegraph passes within this cylinder, traversing which, it is first presented to the inner surface in the form of a thick wire furnished with spurs whose points are in the closest possible proximity to the cylinder without being in actual contact; it is then continued on, and presented as a short coil of very fine wire (finer, in fact, than that of the instrument coils) wound on a bobbin, the outer convolution of the coil being very close to the cylinder. Thus a better means of escape is presented to the lightning than is found in any part of the instrument; consequently it always escapes by this conductor, either by the points or by burning the fine wire. It is found to be perfectly effectual. In Steinheil's method the line wire extending over the station is divided, each end being fastened to a copper plate 6 inches in diameter; the plates are brought close together, but prevented from touching by a silk cloth; then coils of wire pass down from the corners of each plate to the telegraph instrument. The galvanic current is thus enabled to pass; but an atmospheric discharge would break through the small obstacle between the copper plates in preference to passing out of its way through the thin spiral of wire. Since the introduction of this protector in 1846, no derangement of the apparatus is stated to have occurred even with the most vivid flashes of lightning.

(1088) On the Brunswick State Telegraphs, the main wire, well

protected by gutta percha, is passed through pipes underground, and fastened to a copper plate in the telegraph room. From this plate a small insulated wire is extended to the signaling instrument, and through the battery to a second copper plate in connexion with the earth. The two copper plates are screwed together, but insulated from each other by pieces of ivory. The two thin wires, which are covered with silk, are twisted together, but separated near the telegraph apparatus, to the screws of which they are attached. The galvanic current passes through the main wire to the first plate, through the thin wire to the apparatus and electro-magnet, through this to the galvanic battery and the second plate, over this by the stronger insulated wire to the ground, making a perfect circuit. But a discharge of atmospheric Electricity would pass between the two copper plates rather than through the long thin wires, and the telegraph apparatus is thus effectually protected. Various forms of lightning protectors are used in America, the simplest and best seems to be that of Bulkley, which consists of two brass plates with serrated edges, one of which is fixed to a board, the other adjustable by means of a screw to any required proximity to the first; the line wire is connected with the fixed plate, and the moveable one is in communication with the earth; the plates are brought as near together as possible without touching, so that any Electricity of tension may meet with as little resistance as possible in its passage from the line wire to the earth.

(1089) Breguet's *paratonnerre* used on the French telegraph lines, is shown in Fig. 426. The line wire is connected with a very fine iron wire placed in a glass tube, capped at both ends with brass and screwed on to a board. To the side of one of the brass caps is fastened a serrated piece of metal, B; immediately opposite and as close as possible to which is a similar serrated piece of metal, C, in communication with the earth by the wire E, so that if the wire of the line should become charged with atmospheric Electricity, it may discharge itself by these points to the earth; and in the event of a flash of lightning striking the line wire, the thin iron wire A would be fused, and the telegraph instrument protected.

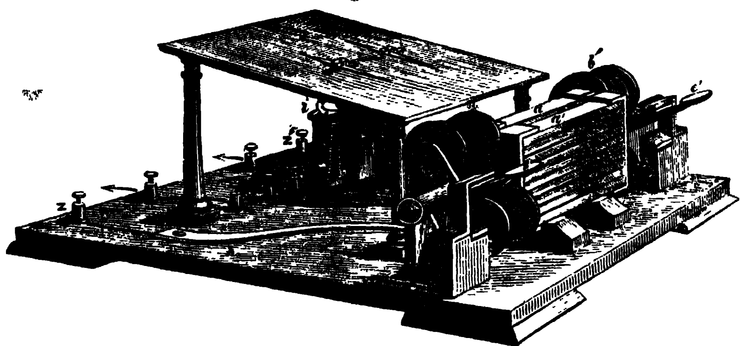
Fig. 426.



(1090) *The Magneto-electric Telegraph.*—In this instrument, patented by Mr. Henley in 1848, the motions of the needles are actuated by the electric currents momentarily induced in electro-magnetic coils when moved in proximity to the poles of a permanent steel magnet. This

telegraph is adopted, with certain improvements, by the English and Irish Magnetic Telegraph Company, through a length of line above 2,100 miles; by it messages are now passed between Liverpool and Dublin direct, a distance of about 420 miles; the line of communication extending *viâ* Port Patrick and Belfast; and signals can be interchanged when necessary between London and Dublin, a distance by the wire of 660 miles, without any break of circuit, or renewal of the magnetic circuit: the whole length of wire in use is about 13,900 miles, of which 6350 miles are laid underground, and about 7,500 above ground. This telegraph, the simplest and the most economical yet invented, merits a detailed description. For the following particulars we are indebted to the kindness of Mr. B. Bright, the secretary of the above company.

Fig. 427.



(1091) The original apparatus of Mr. Henley is shown in Fig. 427. Two compound bar magnets, *a a′*, are fixed parallel to each other, so that their opposite poles are in juxta-position. At each end of the magnets are arranged a pair of electro-magnetic coils, *b b′*, which are connected together at the back by a soft iron armature, *c*; each pair is attached to a separate axle and finger key, *e e′*, and are perfectly independent of each other, so that by their motion they can communicate magneto-electric currents to the two line wires, *z z′*. In order to avoid the friction that would ensue on the motion of the coils, if their soft iron centres were in actual contact with the poles of the permanent magnets, the axles upon which the coils are fixed are so adjusted as to bring the ends of the soft iron cores to within about the $\frac{1}{16}$th part of an inch from the magnets. When the *sending* part of the apparatus is at rest, a spring, *h*, keeps the coils so disposed that the centre of one is before one pole of the magnet, and the other before the other pole. This answers a double purpose; the iron cores and armatures of the coils act as a keeper to the magnets when the apparatus is not in use, and the position at the same time

is such that the maximum of inductive effect is obtained upon the motion of the coils. The finger key attached to the axle, on being depressed, reverses the position of the coils in relation to the poles of the magnets; the alteration in the polarity of the soft iron cores which thereupon ensues, occasions by induction a revulsion in the electric condition of the convolutions of wire forming the coils, and the current induced flows from one terminal wire of the pair of coils, through the indicating portion of the apparatus, *i*, in one direction to the earth, and from the other terminal wire in the opposite direction through the line wire. On the return of the finger key to its original position, the polarity of the cores is again reversed, and currents are induced in the opposite direction to those previously generated. The operation of the one current is to deflect, and of the other to bring back to zero the indicating needles of the apparatus, and of the instruments, at the various stations to which the currents may pass. The motion of the other finger key leads to similar effects being produced in connexion with the other line wire; and the combinations of movements of the two indicating needles constitute the alphabet.

(1092) The indicating portion of the apparatus consists of a pair of small electro-magnetic coils coupled together by an armature; the soft iron cores project beyond the coils, and are terminated by semi-circular horns of soft iron. This elongation of the cores was found necessary in order to prolong the polarization of the coil, as the great intensity of the induced current would not occasion during its passage through the coil a sufficient amount of polarity in the iron to move the magnet of the indicating needle unless its effects were, so to speak, thus temporarily fixed. On the return of the finger key to its original position, an amount of residual Magnetism is left in the horns of the indicating coils sufficient to hold the needle in its position at zero when the instrument is at rest. By this arrangement what is technically termed a "dead beat" of the needle is produced, and the needle at the same time is in perfect equilibrium upon its axle,—conditions which conduce greatly to the rapidity and invariability of the needle's motion, and to the accurate interpretation of the signals. The magnets used to generate the induced currents are tempered in a particular manner, and retain their polarity for years. They are easily remagnetized when required, by bringing their poles for a short time into contact with a powerful electro-magnet.

(1093) *Recoil Currents from Underground Lines.*—The Magnetic Telegraph Company have adopted, to a very great extent, the underground system. In 1851, they laid a line between Liverpool and Manchester; they afterwards extended the system from London

through Birmingham to Manchester, Liverpool, and the various towns in the Lancashire districts, northwards to Scotland, with a submarine cable linking up underground wires laid to Belfast and Dublin. They have been enabled to accomplish this through the great perfection to which the insulation of wire by successive coatings of gutta-percha has been brought by Mr. Statham. It was found upon communicating a charge to a great length of underground wire, that after the withdrawal of the excitation (whether galvanic or magnetic Electricity was employed), an *electrical recoil* immediately took place at the end of the wire to which the current had been previously communicated.* The nature of this phenomenon has been explained by Faraday (316 *et seq.*); its existence was soon found to interfere very materially with the working of telegraphic apparatus, nor does it appear that up to the present time, any adequate remedy as regards the galvanic system has been applied. The nature of the interference will be at once understood, when it is mentioned that, with a letter-printing telegraph, the surplus current has the tendency to carry the machinery on farther, and to make other letters than those intended. With the chemical and other recording telegraphs, the surplus flow of Electricity will continue nearly a minute, entirely confounding the marks, and representing one letter with the next; and with the needle telegraphs, a beat more is made by the back current than intended with every letter formed.* Another remarkable feature to be noticed in connexion with the underground system, is the small comparative velocity with which the electrical impulse is communicated through each conductor in long circuits. Through a circuit of 480 miles, Messrs. Bright found that the difference of time between the communication of the electrical impulse and its arrival at the other end of the wire, amounted to rather more than a third part of a second, which would give as the rate of transmission of the galvanic or magnetic fluids through such conductors, only about 1,000 miles per second. It has been shown by Faraday (316 *et seq.*) that this retardation does not arise from any resistance of the conducting medium, but is the consequence of a *lateral* induction whereby the wire becomes charged *statically* with Electricity,—becomes in fact an immense Leyden arrangement.

(1094) On applying the magneto-apparatus above described to the underground system, it was found impossible to work it without making some provision against the effects of the recoil currents, for when the needle had been deflected and brought back to zero, by the two successive currents generated by the instrument, the recoil

* G. B. Bright, "Shaffner's Telegraph Companion."

current flowing in the opposite direction to the last current sent, again threw the needle over, so that each time a signal was transmitted, instead of two beats of the needle being given, *three* occurred, disorganizing the series of signals employed, and leaving the indicating needles of the sending instrument in such a position as to render the answering signal (given after every word) unintelligible; for of the two currents employed in sending the answering signal from the other end, only the second showed any effect; the first serving to keep the needle against the stop pin, where the recoil current had left it. Moreover, the continual recurrence of two currents in one direction, and only one in the other, for each movement of the finger-key, a residual excess of one kind of polarity accumulated in the indicating coils; and thus after a short time, the effects of currents from the other end were neutralized, and the communication of signals rendered impossible.

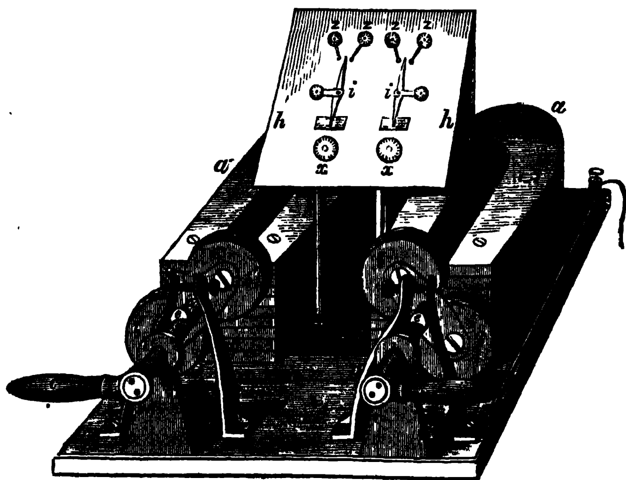
As the reciprocality of two instruments working in a circuit together is almost a *sine quâ non* for correct transmission of signals, and constitutes the most valuable feature of excellence in the English system, it was at once seen that if underground wires were to be worked, this difficulty must be overcome.

(1095) *Messrs. Bright's Improved Magnetic Telegraph.*—It was first sought to obviate the effects of the recoil currents by placing the charged wire into direct connexion with the earth at the instant that the exciting current ceased, so as to prevent the flow of the recoil current from passing through the indicating apparatus, which was again placed in communication with the line wire when the handle had recovered its place of rest. It was found, however, that upon extending the line, the time required for the recoil current to discharge itself increased also; Messrs. Bright then applied another method. The indicating apparatus was altogether disconnected from the action of the sending currents, and only brought into connexion with the line wire at their termination. In this plan, instead of shutting off the recoil current it was permitted to pass through the receiving coils at the close of the sending currents, and the connexions of the apparatus were so arranged that it conduced to the efficient working of the apparatus by keeping the needles at zero, so as to be in the proper position for receiving signals from the opposite ends of the line. A compensating apparatus was also introduced having for its object: 1st, the obviating the effects of the deflecting currents which continually pass through telegraph wires, more or less, and in different directions, and which arise from variations of terrestrial Magnetism, and during aurora borealis and other atmospherical electrical disturbances (311 *et seq.*); and 2nd, the

neutralizing any excess of residual Magnetism that might be engendered in the horns of the coils by the recoil current; this excess varies with the difference in the length of the circuit worked, and requires a *constant* compensation to be maintained. The apparatus consists of a permanent magnet of much greater strength than the magnet within the horns of the indicating coils, fixed upon an axis, at such a distance from the lower pole of the indicating needle, that the poles of the compensating magnet may be made to describe a circle intersecting the lower pole of the indicating magnet, but being in a plane slightly removed from it, so as not actually to come into contact. By an external regulator, the compensating magnet can be adjusted, so that the influence of either of its poles can be brought to exercise a definite influence of attraction or repulsion upon the receiving magnet, and upon the soft iron horns of the coils by which it is moved, and thus to negative an excess of polarity in either direction. Since this contrivance has been adopted not the least inconvenience has been suffered from the greatest electro-terrestrial disturbances, even when to such an extent as to deflect a galvanometer needle at right angles; nor does the strongest return current from the most extended circuit impede in the least the efficient transmission of signals.

(1096) The magnetic telegraph as thus improved and with which the underground wires are now worked, is shown in Fig. 428;

Fig. 428.



a a, compound horseshoe magnets, formed of steel plates screwed tog.

b b, induction coils attached to axles moved by the handles *c c*;

one of the wires terminating each pair of induction coils is connected to an insulated metallic *cam;* the other end of each pair of coils is conducted directly to the earth.

c c, the metallic *cams;* they are insulated from the axles to which they are attached by ivory plates.

f f, two springs connected with the line wires, and resting against the screws of the bearings *g g*.

g g, two bearings, or bridge-pieces, in connexion with the indicating portion of the instrument.

h h, the outside of the dial; *i i*, the indicating needles moved by magnetic needles inside on the same axles.

x x, thumb-screws by which the magnet regulators are adjusted.

z z z z adjusting pins between which the needles beat.

The internal arrangement of the indicating apparatus is not shown in the figure. When at rest, the spring *f* is in contact with the bridge-piece *g*, and the line wire is in direct communication with the indicating part of the instrument, and the electric currents from other stations pass from the line wire through the indicating coils, and thence to the earth, producing in their passage the required signals. When, however, the handle is depressed, the metallic *cam* or stud attached to the axle presses the spring away from the bearing *g*, and the current of Magneto-electricity produced in the induction coils by their change in position, as regards the pole of the permanent magnet, passes direct to the line wire; this current deflects the needles of other stations from zero. Directly the downward motion of the handle is arrested, and during its return to its original position, a current in the opposite direction is induced, and flows through the line wire, bringing the indicating needles of the other stations back to zero, but not affecting its own indicating apparatus, owing to the connexion between the spring and the bearing being still incomplete. The moment the spring is again in contact with the bridge-piece, on the cam setting it at liberty, the line wire, in which a portion of the last current has been *fixed*, as it were *in transitu*, seeks to gain its equilibrium, and the recoil current passes through the indicating portion of the instrument (now in circuit again), and holds the needles to zero, in the proper position to be actuated by currents from the other stations.

(1097) *Messrs. Bright's Acoustic Telegraphic Apparatus.*—Under the ordinary system of telegraphing, it is necessary to employ a transcriber to write down the words as interpreted from the visual signals, and dictated to him by the receiving operator, whose eyes being fixed on the rapidly moving needles, could not be engaged in conjunction with his hands in writing. It was found that owing to

the frequent occurrence of words of nearly similar sound, the transcribers sometimes unavoidably misunderstood the meaning of the receiving operator's, and altered the sense of the despatch by writing the wrong word. Such words as "two," "too," "to;" "four," "for;" "hour," "our," may, for instance, be very easily confounded. Messrs. Bright have sought to remedy this inconvenience by transferring the manifestation of the effects of the current from the eye to the ear. Their apparatus is shown in Figs. 429 and 430.

Fig. 429.

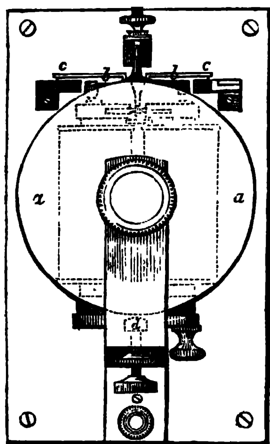
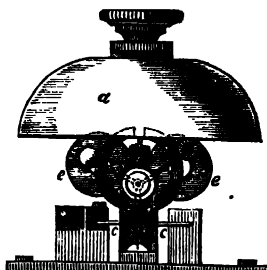


Fig. 430.



a is the bell; *b*, the hammer; *b'*, the muffler to deaden the sound, and stop the vibration after each stroke; *c*, the contact maker and breaker, by which the local battery is put on and shut off; *d*, a fixed muffler; *e*, *e*, Fig. 429, the electro-magnetic coils through which the local current is passed, and which actuates the magnet *i*, from the axle of which extend arms bearing the hammer and muffler *b b'*.

There are usually a pair of these bells together, one bell differing half an octave in tone from the other, and one being fixed to a wooden partition, one on one side, and the other on the other side of the operator. From the number of beats, and the difference in tone, the letters and words are formed in the same manner as with the needle telegraph.

(1098) Besides the saving in staff and in mistakes, any injury to the eyes of the clerks is prevented, and an appeal is made to an organ far better capable of endurance and accurate interpretation; and it is found that a greater speed can be attained than by the old plan of telegraphing by needles, and the prompt attention of the operator is at once directed to the instrument, by the sounds given, upon a call being made. It is worthy of note, that while to read by a visible signal a movement of at least the eighth part of an inch is necessary for accuracy, the local current of the acoustic apparatus produces the full sound by the slightest movement, even the $\frac{1}{100}$th part

of an inch of the magnet actuated by the primary current proceeding from a distant station. The idea of assisting the telegraphic operator in interpreting visual signals, by releasing the detent of a train of clockwork, and so producing intonation of an alarum to mark out the number and period of the beats of the needle more distinctly, appears to have been suggested in this country about twelve years ago, but practical difficulties at that time prevented its application. A similar plan without, however, the employment of local currents, was proposed in Germany in the early days of electro-telegraphing, but it was not successfully carried out. We are informed, however, that some of the most busy circuits in connexion with the English and Irish Magnetic Telegraph Company are now worked by this method at the rate of from 30 to 40 words per minute, received and written down by the *same* operator.

(1099) The following details of the system of underground wires have been kindly furnished by Mr. Bright:—

It was evident that the integrity of the insulating coatings of gutta percha could not be preserved long without some external protection throughout the length of each line, as the mere compression of the soil, gravel, and stones would at once have injured it, and in opening the roads for repairs, they would experience still further damage; after discussing the merits of various plans of protection, it was finally decided that the wires throughout towns should be laid in cast iron piping, divided longitudinally, so that the wires might be laid in quickly, without the tedious and injurious operation of drawing them through, as was the case with the old system of street work, where the wires were laid in ordinary gas piping; and that along the country roads, which were comparatively little liable to disturbance from the construction of sewers or laying of gas or water pipes, the wires should be laid in *creasoted* wooden troughs, of about 3 inches scantling, cut in long lengths, so as to be little liable to disturbance upon any partial subsidence of the soil, which not unfrequently occurs in districts where mining operations are carried on. The tops of the troughs are generally protected by fastening to them a galvanized iron lid.

Fig. 431.

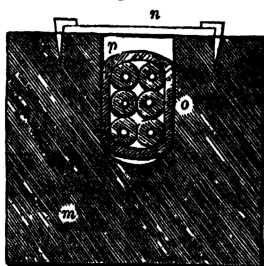


Fig. 431 shows a section of one of the troughs: *m* being the trough; *n*, the galvanized iron lid; *o*, the gutta perchaed wire; and *p*, a lapping of tarred yarn. The trough is deposited at a depth of 2 feet from the surface of the road. The iron piping used in towns is about 2½

inches in diameter. The lower halves are first laid, socket into socket, in the trench, and the wires are then rapidly reeled off, and deposited in the lower halves from a drum drawn over the trench. The upper halves are then laid on, and attached to the already laid portions by clamps or bolts fastening through ears cast in the sides of the pipes. So well has this mode succeeded that in Liverpool the whole lengths of the streets from Tithebarn railway station to the office in Exchange Street East were laid down in a single night; and in Manchester, the line of streets from the railway station in Salford to Ducie Street by the Manchester Exchange, in 22 hours.

(1100) In the overground system, the wires are arranged upon insulators attached to arms of different lengths, so that if a wire breaks and falls off it does not come into contact with those below, so as to impede the transmission of signals, but falls clear. The insulators are of glass or earthenware, of the form shown (side view and section in Figs. 432 and 433). The wires pass through a groove in the top of the insulator, and are secured there by a small peg and lapping of binding wire.

Fig. 432.

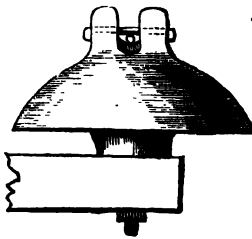
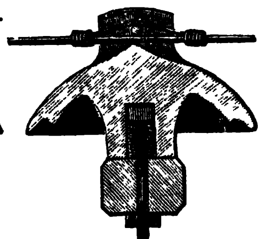
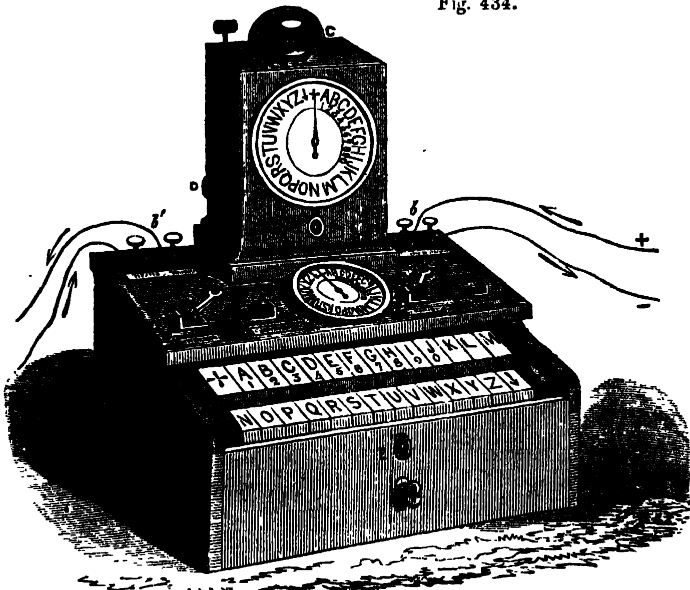


Fig. 433.



(1101) Froment's French alphabetic tele-

Fig. 434.



graph shown in Fig. 434 is an exceedingly elegant piece of apparatus. In external form it resembles a small pianoforte without the black keys. There are 28 keys: 26 representing letters, 1 a cross, and 1 an arrow; by pressing down any key its corresponding letter is shown on the dial, and at the same time on the dial of a similar apparatus at the distant station. Suppose, for example, the apparatus figured in the text to be at Paris, the current from the pile enters the apparatus at *b* and leaves it at *b'*; it proceeds thence to the distant station—say Rouen—where it traverses and works a precisely similar apparatus.

(1102) The mechanism of the internal part of the apparatus will be understood from a slight consideration of Figs. 435 and 436.

Fig. 435.

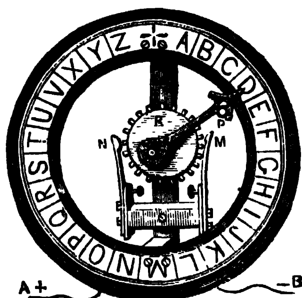


Fig. 436.

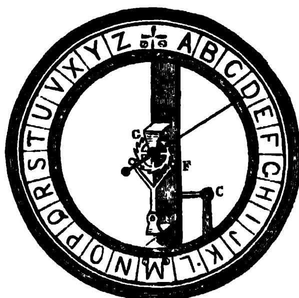
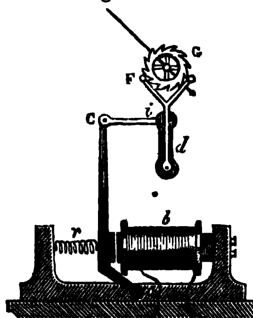


Fig 435 is the *manipulator*, or the instrument for giving signals; Fig. 436 is the *receiver*. The current from the battery enters through A, Fig. 435, passes up the brass spring N, which is in contact with the wheel R, and from this through the second notched spring M, out by the wire B, and on along the line wire to the telegraph at the distant station. There the current traverses the bobbin of an electro-magnet, not seen in Fig. 435, but exhibited separately in Fig. 437. This electro-magnet is fixed horizontally at one extremity, the other being left free to operate on the soft iron armature *a*, which forms part of a bent lever, moveable round the pin *o*; the lever is restored to a vertical position when the electro-magnet is no longer active by the action of the spring *r*. The moment the electrical current traverses the bobbin, the lever at C is attracted, and the motion is imparted to a second lever *d*, through the shank *i*. This second lever is fixed on a horizontal axis, and is united to the fork F. When the current is interrupted the spring pulls back the lever, and

Fig. 437.



thus a step by step movement is given to the fork, which it transmits to the wheel G carrying the index.

(1103) The manner in which the battery current is interrupted and renewed will be understood by referring to Fig. 435. The wheel R carries 26 teeth; on turning it by the button P, while the plate N is, from its curved form, in constant contact with the teeth, the plate M, being crooked, has its contacts broken and renewed every time it passes over a tooth, and at the same time the battery current is thrown off and on. Suppose the pointer P is advanced 4 letters, then the current between N and M will be 4 times made and 4 times broken, and the armature of the electro-magnet at the distant station will be 4 times attracted and 4 times pulled back by its spring; but these 4 attractions will give 4 movements to the wheel G, and the pointer will pass over the same number of letters in the dial of Fig. 436, the *receiver*, as in that of Fig. 435, the manipulator. At the top of the case of the instrument is the alarum, which is worked by a special electro-magnet. Referring now to Fig. 434, we see in front of the apparatus a series of 28 ivory keys, the first being marked with a cross, the last with an arrow, and the intermediate 26 with the letters of the alphabet; the first 10 letters carrying also the 10 numerals. Immediately in front of the keys, on a horizontal platform of mahogany, is the dial B and 2 small metal pieces, *m n*, which are moveable, and which by means of a handle may be brought into contact, *m* with *s* or *r*, and *n* with *q* or *p*. The dial B is the verifier; its index must always point to the same letter as that last signalled; if it does not, it shows that the apparatus is not in proper working order. When *m* is in contact with *s*, the apparatus is in a condition to send signals from Paris to Rouen. When in contact with *r*, it is in a condition to receive a signal from Rouen to Paris. In like manner when *n* is in contact with *q*, the alarum may be sounded at Rouen; when in contact with *p*, the machinery is in a state to receive a notice from Rouen.

(1104) *Electro-magnetic Clocks.*—Mr. Bain, who has patented several applications of Electricity to useful purposes, exhibited in the spring of 1841, at the Polytechnic Institution, an electro-magnetic clock, the principle of which will be clearly understood by an inspection of Figs. 438 and 439.

B, Fig. 438, is a back view of an ordinary clock, with a pendulum vibrating seconds; *C*, a plate of ivory affixed to the frame of the clock, in the middle of which is inserted a slip of brass in connexion with the positive pole of the battery. To the pendulum is attached a very light brass spring, *F*, in such a manner, that every vibration of the pendulum brings the free end of the

spring into contact with the strip of brass, thus completing the electric circuit, which is broken as soon as the spring touches the ivory. A series of *electric clocks* may be connected, by means of the wires, with this clock, and if a voltaic battery be included in the circuit they will all go together.

(1105) Fig. 439, is a back view of one of the electric clocks: *a* is

Fig. 438.

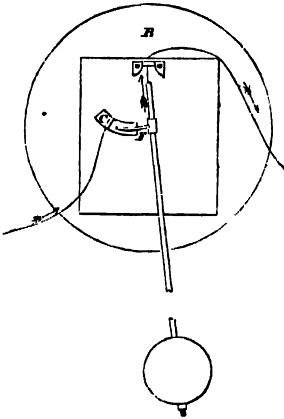
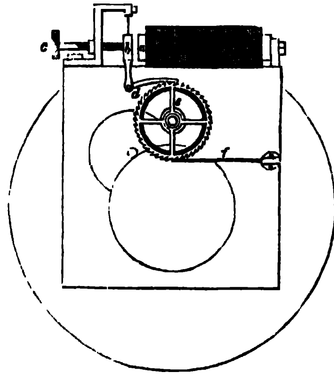


Fig. 439.



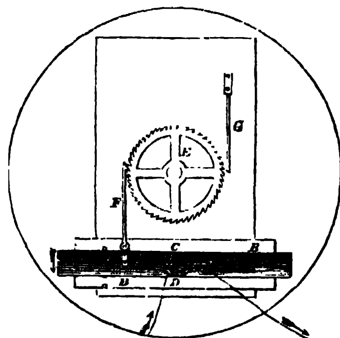
an electro-magnet, and *b*, its feeder, suspended by a spring pendulum-fashion; *c* is a small screw to regulate the distance of the feeder from the electro-magnet. At the lower end of the feeder is jointed a light click lever, *d*, falling into the teeth of a ratchet wheel *e*; *f* is a spring to keep the ratchet wheel steady. When the pendulum of the clock sends an electric current through the conducting wire, the feeder is attracted by the magnet, and the click lever *d*, takes over 1 tooth of the ratchet wheel; upon the current being arrested (by the spring *F* of the pendulum, leaving the slip of brass in the primary clock), the feeder falls back into its former position, and causes the click lever to draw the ratchet wheel 1 tooth forward. The arbor of the ratchet wheel carries the *seconds' hand*, which is thus taken forward 1 degree every second, corresponding to the vibration of the clock *B*. A pinion on the ratchet arbor gives motion to other simple wheel-work, which carries the minute and hour hands. When a large number of clocks is to be worked, the ratchet wheel is placed on the arbor of the *minute hand*, and is moved every minute instead of every second. An ivory circle, with slips or studs of metal, inserted flush with its face, corresponding to the number of clocks or group of clocks intended to be worked, is fixed on the face of the regulating or primary clock; in the centre of this circle is placed

the arbor of the seconds' hand of the clock, upon which is fixed a slight metal spring with its free end in contact with the ivory circle. The conducting wire from the positive pole of the battery is in connexion with the framework of the clock; every time, therefore, that the seconds' hand passes over a metal stud in the ivory circle, an electric circuit is completed and a current transmitted to the clock or group of clocks in connexion with that particular stud. As the seconds' hand passes over every portion of the circle once in each minute, the whole number of clocks thus connected with the regulating clock will be moved forward 1 degree every minute. By this means a large proportion of electric power is saved, for the battery has only a single clock or a small group of clocks to work at the same instant of time.

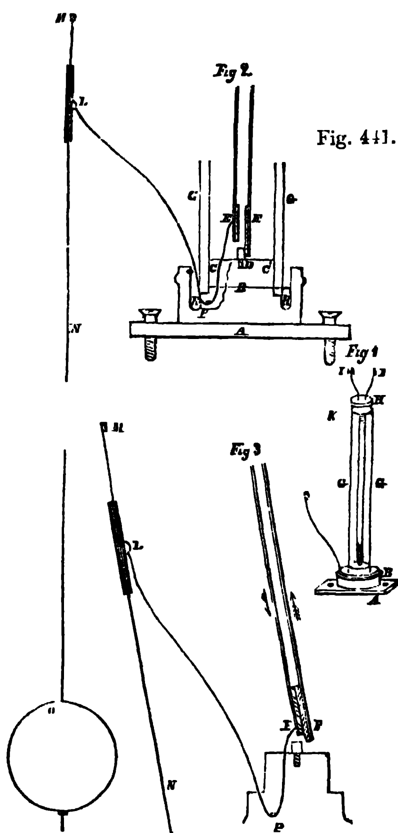
(1106) Mr. Bain has also invented an apparatus for making ordinary clocks keep correct time; also a method of working the electric clock by the deflection of the wire coil. In conjunction with Mr. Barwise, he took out a patent for these inventions, which was sealed 8th January, 1841. On the 28th of March, his clock was exhibited at the Polytechnic Institution.

Fig. 440, shows the method adopted by Mr. Bain for working the electric clock by the deflection of the *wire coil*, instead of the attractive power of the electro-magnet. *A* is a coil of insulated copper wire, freely suspended on centres. *B* is a compound permanent steel magnet, immoveably fixed within the coil. *C C* are two spiral springs, one on each side, for the purpose of conveying the electric current from the stationary conducting wire *D*, to the moveable coil. *F* is a click lever attached to the coil. *E* is a ratchet wheel fixed upon the minute-hand arbor of the clock, and *G* a wheel to keep the spring steady. The regulating clock transmits the electric current to the wire coil, upon which the left hand end is instantly depressed, and the clock lever *F* draws the wheel *E* forward 1 tooth. When the flow of Electricity from the regulating clock is discontinued, the wire coil resumes its original horizontal position by the action of the spring *C*. If the clock receives an electric current once in every second, the wheel *E* is placed on the arbor of the seconds' hand; but if the Electricity is only transmitted once in each minute, then the wheel *E* must be placed on the spindle of the minute hand.

Fig. 440.



(1107) The Rev. F. Lockey's contact-former for the electro-magnetic clock is shown in Fig. 441. Fig. 1 shows the contact-former entire; in each figure similar letters refer to similar parts. On the base board *A* (about 3 by 2 inches) is fixed the circular box or trough *B*. Fig. 2 exhibits a section of this box-wood trough wherein is turned the channel *R R*, and the central part, *C C*, is left as a solid cylinder on which to place rather firmly the glass tube *G G*. This tube, of which *G G* in Fig. 2 shows the section, rests on a rim or shoulder just below the rim at *B*, which shows the level to which mercury is poured into the channel *R R*, for the purpose of closing the bottom of the tube, and preventing all access of dust to its interior. The glass tube is surmounted by an ivory cap, *H*, Fig. 1, cemented thereon; through the ivory cap pass the two wires *I I*, furnished with screw connecting pieces for the purpose of uniting them with the *p* and *n* wires of the galvanic battery. The lower end of these wires terminates in two very thin and flexible copper springs, of which the lower portions are seen in Fig. 2, *E F*; they are tied together at *K*, Fig. 1, a piece of ivory being interposed to prevent metallic contact, as well as to place them parallel to each other in the tube; they are tipped with platinum foil at *E* and *F*, and one of them is a little longer than the other. The spring *F* is so set as to have a slight tendency to advance towards *E*, but it is prevented from doing so by the ivory stud *D*, Fig. 2. Part of the central cylinder *C C* is supposed to be broken away in Fig. 2 to show the lever (formed of iron wire No. 18) bent somewhat in the form *E C P L*, the fulcrum *P* being beneath the end of the tube, and the part *E C P* working freely in a slit in the cylinder *C C*. If this contact-breaker


Fig. 441.

is intended to work an electro-magnetic clock, it is so placed at the side of the central or regulating clock, as that the pendulum *M N O*, just before it swings into a perpendicular position, shall begin to act on the lever at *L*. During the remaining half of its vibration towards the right hand (in the figure), as well as during the first half of its returning vibration towards the left hand (see Fig. 3) it will *maintain contact* between the free or platinum ends of the springs *E* and *F*; during the other two halves of its vibrations, the lever is unacted upon, and the springs returning to their parallelism, contact is broken, and the battery current ceases. Such an instrument does not impede the action of the clock to which it is applied; Mr. Lockey's had been upwards of six months in continuous use, and acting with unfailing accuracy, when the author first saw it.*

(1108) Mr. Wheatstone's electro-magnetic clock, which was exhibited and explained at the Royal Society, 25th November, 1840, is thus constructed: all the parts employed in a clock for maintaining and regulating the power are entirely dispensed with. It consists simply of a face with its second, minute, and hour hands, and of a train of wheels which communicate motion from the arbor of the seconds' hand to that of the hour hand, in the same manner as in an ordinary clock train; a small electro-magnet is caused to act upon a peculiarly constructed wheel placed on the seconds' arbor, in such a manner that whenever the temporary Magnetism is either produced or destroyed, the wheel, and consequently the seconds' hand, advance $\frac{1}{60}$th part of its revolution. On the axis which carries the scape wheel of the primary clock, a small disc of brass is fixed, which is divided on its circumference into 60 equal parts; each alternate division is then cut out and filled with a piece of wood, so that the circumference consists of 30 regular alternations of wood and metal. An extremely light brass spring, which is screwed to a block of ivory or hard wood, and which has no connexion with the metallic parts of the clock, rests by its free end on the circumference of the disc. A copper wire is fastened to the end of the spring, and proceeds to one end of the wire of the electro-magnet; while another wire attached to the clock frame is continued until it joins the other end of that of the same electro-magnet. A constant voltaic battery, consisting of a few elements of very small dimensions, is interposed in any part of the circuit. By this arrangement the circuit is periodically

* The cost of working an electro-magnetic clock, according to Mr. Tylee's observations, is under a penny per week, the battery employed being one on Smee's construction, platinized silver, 3½ inches square, and the exciting fluid, water with $\frac{1}{20}$ part of sulphuric acid. Such a battery Mr. Tylee finds will work his clock for 14 days without being interfered with.

made and broken, in consequence of the spring resting for one second on a metal division, and the next second on a wooden division. The circuit may be extended to any length, and any number of electro-magnetic instruments may be thus brought into sympathetic action with the standard clock. It is necessary to observe, that the force of the battery and the proportion between the resistances of the electro-magnetic coils and those of the other parts of the circuit, must, in order to produce the maximum effect with the least expenditure of power, be varied to suit each particular case.

(1109) The next step in the progress of the invention of electric clocks, was the application of the electric power to work single clocks, so that no winding might be required, and the common clock dispensed with altogether. Mr. Bain's arrangements for effecting this are shown in Figs. 442, 443.*

Fig. 442 is a representation of an electric pendulum, suspended from a metal bracket, *h* ; the bracket being firmly fixed to the board AA, which is, in a finished clock, the back of the clock-case. The pendulum-rod is of wood. B the bob of the pendulum, is composed of a reel of insulated copper wire, having (merely to improve the appearance) a brass covering; the ends of the wire are carried up the rod, and terminate in two suspension springs, *i* and *j*, which serve the double purpose of suspending the pendulum, and conveying Electricity to and from the wire in the bob B. *nn* are two brass tubes fixed to the sides of the case, and facing each other. *a b c f g* is an apparatus called the *break*, for letting on and cutting off the electric current to and from the wire in the pendulum B, and performing the same office for clocks in distant places. Z is a plate of zinc buried in the ground. C is a plate of copper, or what is equally good, a quantity of carbon (common coke or wood charcoal). In private houses and other establishments in town, the ground underneath the floor of the coal-cellar, or the flags of the area, is a suitable position for sinking the plates, or in any place where free access may be had to the moist soil. In country establishments there will be no difficulty, as the plates may be sunk as above, or in any part of the garden. D and D[1], are wires connecting the zinc and carbon with the pendulum. These wires should be entirely insulated, and for this purpose gutta percha covering is the best material; thus protected, they may be carried to any distance in any manner most convenient. The zinc and carbon should be buried in the soil, at least 3 feet deep, and should not be less than 4 feet apart. To unite the wire D with the zinc plate, it must be simply soldered; but in uniting the wire D[1] with the carbon, a piece of platinum wire

* History of Electric Clocks, by Alexander Bain.

must be soldered to the end of the copper wire, and the other end of the platinum wire tied firmly round a small piece of the carbon,

Fig. 442.

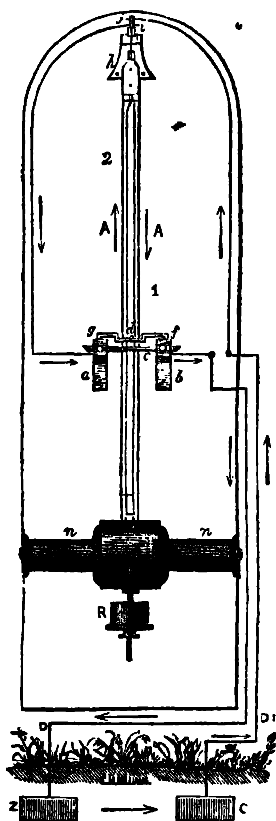


Fig. 443.

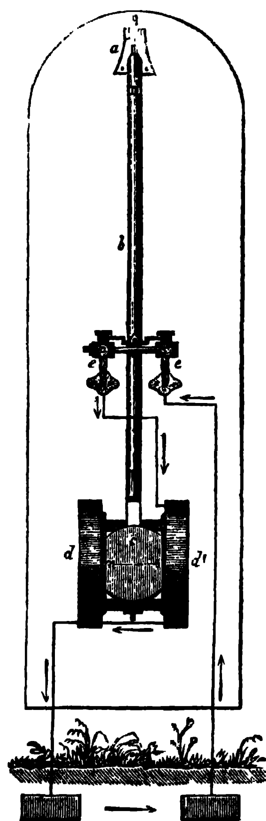


Fig. 444.



and placed in the centre of the mass. Especial attention must be given to this, as it has been found, in every instance, that if the copper wire come into contact with the carbon it will inevitably corrode. Another plan equally good, is to drill a small hole in a piece of the carbon, and drive in a plug, likewise made of carbon, with the end of the platinum wire. If the plate C be composed of copper, it will simply be necessary to solder the copper wire to it. The break is composed of two metal standards, *a* and *b*, fixed to the back of the case; *c* is a wooden or ivory bar, fixed (but easily move-

able) in the standards, by means of binding screws. On the surface of the end of the wood or ivory bar *f*, is inserted a strip of gold, concave on the upper surface, as seen at F, Fig. 444, which is in metallic contact with the standard *b*. At the end *g*, of the bar, is inserted (bound in a metal ring) a small piece of agate, and a piece of gold, both semicircular, represented by Fig. 444; the light part being the gold, the dark part the agate, with a shallow groove cut in the surface of each, similar to that in the gold at F, in fig. 444. In the grooved part of the agate, and perfectly flush with the surface, is inserted a plug of gold. The plug of gold is in metallic connexion with the bracket *a*. The semicircular piece of gold is to form the connexion with other clocks at a distance. *f g* represents the thin-kneed bar, the ends of which rest and slide freely in the grooves or concave parts already described. R is the regulating weight, which brings the pendulum to time. The opening in the interior of the reel B is large enough to permit the pendulum to vibrate freely, without the liability of touching the tubes *n n*. The suspension spring *j*, being connected by a wire with the carbon, if the end of the kneed bar rest on the gold plug in the agate, the electric circuit will be complete, and the course of the current may be thus described. The current is supposed to begin at the plate of zinc in the ground, thence through the moisture of the earth (a sufficient conductor) to the carbon, then through the wire D', as shown by the arrows to the spring *j*, through the spring down a wire, to the coil of insulated wire in the bob B, which it permeates, and thence, by the wire 1, to the spring i, to the bracket *a* of the break, through the gold plug in the agate, to the point *g* of the bar *g f*, then through the bar to the bracket *b*, and returning by the wire D to the zinc plate, as shown by the arrows.

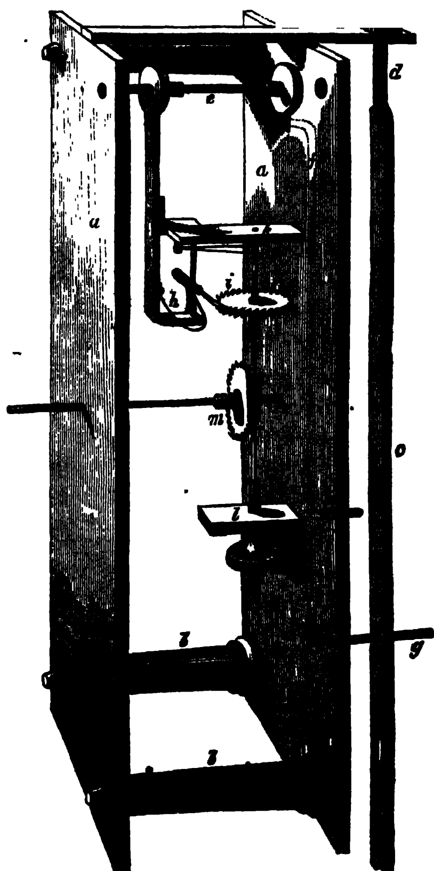
(1110) The mechanism and the means of establishing the galvanic power being thus explained, the manner of its operation remains to be shown. While the Electricity is thus passing, it renders the coil of wire in the bob B magnetic, that is, it gives it all the properties of a magnet with dissimilar poles, N. and S. In the diagram, the N. pole is to the right hand, and the S. to the left. Now, the permanent magnets having their N. poles inwards next to the coil, it is evident, by the well known law of Magnetism, that the N. pole of the left hand magnet will attract the S. pole of the coil, while at the same instant the N. pole of the right hand magnet will repel the N. pole of the coil, and by these means the pendulum will receive an impetus towards the left. It cannot under these circumstances hang perpendicular, but if the galvanic current is broken (which can be done by sliding the bar *g f* a little to the left,

till the point is off the gold plug), the coil being no longer magnetic, the magnet will have no further effect upon it; the pendulum is therefore free to go back in the contrary direction. The pendulum itself gives motion to the sliding bar, by means of the pin *d*, which projects from the rod, and acts in the kneed part of the bar. If we now take hold of the pendulum with the hand, and move it to the right, till the point of the bar is on the gold plug, and then let it swing back, it receives an impulse from the magnets, as just explained. When it arrives at the end of its excursion to the left, it will of itself push the sliding bar off the gold plug; the power will then cease, and it is free to return to the right hand by its own momentum, until it pushes the sliding bar again on to the gold plug- and thereby receiving another impulse, will continue its vibrations, which will increase in length, till the point of the sliding bar is carried beyond the surface of the plug on the right, and partly on to the agate, this action cutting off a great portion of the electric current, and if the vibration further increase in the smallest degree, the power during one vibration is entirely cut off. In this way the pendulum is kept precisely at one given arc of vibration, however variable the electric current may be, provided only that there be always sufficient. It may be here remarked, that the lower the break is placed with reference to the pendulum, the greater will be the accuracy of its vibration. This governing principle of the break is a most important feature in the invention, and is accomplished without any extra work or friction. For large church clocks an apparatus termed a mutator is employed, which, instead of cutting off the current, changes its direction, so that the pendulum receives its impulse, both from right to left, and left to right, but it has the same governing principle as the break just described.

(1111) Fig. 443 is a representation of another pendulum, with its earth-battery and connecting wires. In this arrangment the permanent magnets are in the bob of the pendulum, and the coils of wire are fixed to the case; or, in other words, the permanent magnets move, and the temporary magnets, viz., the coils of wire *d, d,* are fixed. *b* is the pendulum-rod, suspended in the ordinary way by a single steel spring to the bracket *a*. *c c* are two semicircular permanent steel magnets, having N. poles pointing to the left, and S. poles pointing to the right. *d, d* are two oblong coils of insulated copper wire, fixed to the back of the case, the opening in the coils being large enough to allow the bob of the pendulum to move freely without the liability of touching; the break in this case is the same in principle and action as that already explained, but the connecting parts are covered with brass caps to exclude the dust, and the brackets are more ornamental. The

action is as follows: When the galvanic current is let on, the coil d attracts the N. poles of the magnets of the pendulum-bob, at the same time the coil d^1 repels the S. pole; the pendulum thus gets its impulse to the left, and the current being cut off by the break, as explained in Fig. 442, the pendulum is free to return by its own momentum, and the motion is thus perpetuated. It will be observed that these pendulums are moved not by mechanical means, which involve friction and wear, but by magnetic power, in which there is none of either, and even that power is applied, *at the utmost*, in every second vibration, though in actual practice it is not in full force more than once in every fifth vibration, the only friction (which is very slight) being the sliding of the bar *g f*, of the break; it may, therefore, be safely inferred that these are the most detached pendulums ever yet contrived. They are regulated to time in the ordinary way, by raising or lowering the weight R, or by raising or lowering the bob itself.

Fig. 445.



(1112) Fig. 455 represents the mechanism by which motion is given to the hands; there are but two wheels in the train, besides the dial-wheels, and as these are moved in the ordinary way, they are not shown in the figure. *a a*, are the frames, fitted to each other in the usual manner; fixed to the top of the frames is a cross bar to which the pendulum may be suspended (Mr. Bain, prefers suspending it as shown in Fig. 455); *c* is the top portion of the pendulum-rod, which is suspended at *d*; *f* is the crutch, shown by two dotted lines, having its axis at *e*— on the same axis is the arm

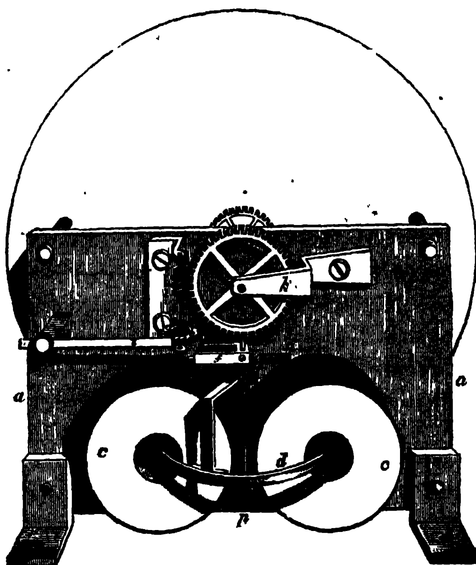
h, which carries the click *i*; *k* and *l* are projections from the inner part of the back frame; these are the bearings of a spindle, which carries the ratchet-wheel at *i*, and a worm which works into the teeth of the wheel *m*, the arbor of the wheel projecting through the front frame. The action takes place as follows: the pendulum-rod, in its excursion to the left, comes against the projecting pin *g*, which is fixed in the lower end of the crutch, and pushes it aside; this action gives similar motion, through the crutch and axle *e*, to the arm *h* and click *i*: this causes the point of the click to slip over one tooth of the rachet-wheel. Now, when the pendulum takes its excursion to the right hand, the crutch follows by means of its own weight (or a small weight attached to it), and the click *i* pushes the rachet-wheel forward the space of one tooth, the worm gives motion to the wheel *m*, and this gives motion to the dialwork and hands in the usual manner.

(1113) But the electric pendulum does more. It not only gives motion to the clock, or rather indicator, which is in the case with it, by mechanical action, but it lets on currents of Electricity to other clocks or indicators at any distance; and this important object it accomplishes without any extra wear or tear, and without any friction; for it will be perceived in the previous explanation of the break, that when the point *g* of the bar is off the gold plug which is in connexion with the pendulum, it is moved on to the gold grooved plate which is connected with the distant clocks, thus letting on the current to the pendulum and clocks at a distance alternately. By this arrangement there is a great economizing of electric power, as when the current is cut off from the clocks it is working the pendulum; when cut off from the pendulum it is working the clocks; and thus there is no moment when the electric current is not in practical operation.

(1114) Fig. 446 represents the mechanism of one of the affiliated or companion clocks. *a a* is a brass plate to which the dial and all parts of the mechanism are fixed; *c c* are reels filled with insulated copper wire; *d* is a semicircular permanent steel magnet, a similar one being on the other side. These magnets are fixed to an axle by means of arms, poles of the same name being opposite each other, viz., N. to N., and S. to S., and the poles vibrate freely in the interior of the coils. These coils are joined to, and form part of, the electric circuit with the parent clock, and by the transmission of electric currents from thence the magnets *d* vibrate in unison with the pendulum.

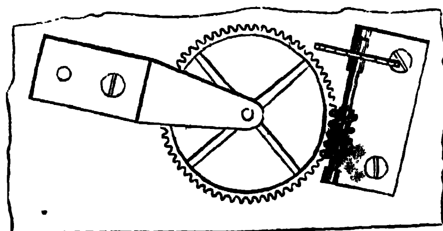
(1115) Having thus obtained uniform motion between the pendulum of the parent clock and the magnets of the affiliated ones, it remains

Fig. 446.



to be shown how motion is given to the hands of the latter. *f* is a small frame, fixed on the same axle as the magnets. This frame carries the little click *g*, which acts in the teeth of the ratchet-wheel *h*; this wheel is carried by the spindle *i*, on which is a screw or worm working in the teeth of the wheel *n* more clearly shown in Fig. 447; the axle of this wheel projects through the plate *a a*, and gives motion to the hands in the ordinary way. *l* is a straight steel spring to keep the rachet-wheel from going back with the click. *k* is a bearing for one end of the axle of the wheel *n*; the other bearing is in the plate *a a*. *b* represents the back of the dial-plate. Mr. Bain tested the correctness of this principle in 1846, by working

Fig. 447.



a clock at Glasgow, by an electric pendulum in the telegraph station at Edinburgh, a distance of 46 miles. The two clocks went accu-

rately together,' the magnet of the companion clock at Glasgow vibrating in unison with the pendulum in Edinburgh.

(1116) *Shepherd's Electro-Magnetic Clock.*—In this beautiful apparatus, well known to the frequenters of the Great Exhibition in 1851, Electro-magnetism is the moving power. The pendulum is so arranged as to make and break an electric circuit, and consequently to make and unmake a horse shoe magnet at each vibration. Each time that the magnet is made it attracts an armature, which lifts certain levers; one of these is concerned in raising a weighted lever and causing it to be held up by a detent or latch; the magnet is then unmade in consequence of the pendulum breaking the circuit, and the armature is released, when the pendulum lifts the latch, and allows the weighted lever to fall, which in falling strikes the pendulum so as to give it an adequate impulse; then the circuit is again completed, the armature attracted, the levers moved, the weight raised and held up by the detent; another vibration breaks the circuit, and releases the armature, the pendulum then raises the detent, the weight falls, and in falling, its arm strikes the pendulum, and gives it an impulse, and so on.

(1117) But the pendulum at each vibration not only makes and breaks the electric circuit of the battery, which maintains it own action, but also, and simultaneously, that of a second battery, of which the duty is to make and unmake the electro-magnets belonging exclusively to the clock or clocks which are upon this circuit. These electro-magnets act upon the extremes of one or more horizontal bar-magnets, so as alternately to attract and repel their opposed poles, and which carry upon their axis the pallets, by the alternating motions of which to the right and the left, the ratchet wheel is propelled onwards at the rate of a tooth each second, and the axis of this ratchet wheel carries the pinion which moves the other wheels of the clock.

(1118) The circuit of the battery connected with the striking part of the clock is only completed once in an hour, and is connected with an electro-magnet, so arranged as by means of a proper lever to pull the ratchet wheel attached to the notched striking wheel 1 tooth forward every 2 seconds, and each tooth is accompanied by a blow on the electro-magnetic bell. The number of blows depends upon the notched wheel, the spaces on the circumference of which are adapted to the number to be struck, and when this is complete, a lever falls into the notch, and so doing cuts off the electric current, which is not re-established through the striking electro-magnet till the next hour, when a peg upon the hour wheel pushes the striking

lever forward, so as to cause it to be depressed by a similar peg upon the minute wheel.

(1119) Shepherd's clocks are adopted in the extensive warehouse of Mr. Pawson, in St. Paul's Churchyard, where eight dials are maintained in action by an electro-magnetic pendulum in the counting-house; they are also used at the Greenwich Observatory, at the Tunbridge station of the South Eastern Railway, &c.; indeed, the time is probably not far distant when clock power will be applied to all the principal cities and towns in Europe, as water and gas are at the present day.

CHAPTER XXI.

DIAMAGNETISM.

Action of Magnetism on Light—Action of Magnets on the Metals—Action of Magnets on Air and Gases—The Magne-Crystallic Force—Diamagnetic Polarity—The Polymagnet—Diamagnetic Conditions of Flames and Gases—Magnetic Conducting Power—Atmospheric Magnetism.

(1120) *Action of Magnetism on Light.*—On the 27th of November, 1845, Professor Faraday communicated to the Royal Society a memoir, in which he made known the interesting fact, that when the "line of magnetic force" (by which he understands that exercise of magnetic power which is exerted in the lines usually called "magnetic curves") is made to pass through certain transparent bodies parallel to a ray of polarized light traversing the same body, the ray of polarized light experiences a rotation. The experiment was made in the following manner. A ray of light from an argand lamp polarized by reflection was passed through a Nicol's eye-piece,* revolving on a horizontal axis. Between the polarizing mirror and the eye-piece the poles of an electro-magnet, each of which would sustain from 28 to 56 pounds, were arranged. The poles were separated from each other about 2 inches in the direction of the line of the ray, and so placed that, if on the *same* side of the polarized ray it might pass near them, or if on the *contrary* side, it might go between them, its direction being always parallel, or nearly so, to the magnetic lines of force. A piece of *silicated borate of lead* glass was placed between the poles, so that the polarized ray should pass through its length. The eye-piece was now turned in such a position that the image of the ray was invisible. On now causing the electric current from a Grove's battery of 5 cells to circulate the iron, the image of the lamp-flame became visible, and continued so as long as the iron continued magnetic, but on stopping the current, the light instantly disappeared. The force impressed upon the *diamagnetic* † was one of rotation, as the light could be extinguished

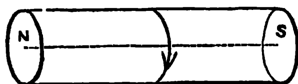
* The arrangement known as "Nicol's prism" consists of a rhombohedron of *calcite* (doubly refracting spar) split into two wedge-shaped portions by a plane passing through two opposite solid angles, and perpendicular to the principal plane, which passes through the same angles; the two wedges are cemented together with Canada balsam, which, while it allows one of the doubly refracted rays to be transmitted, banishes the other ray altogether from the field of vision.

† By "diamagnetic" is meant a body through which lines of magnetic force are passing, the same not being magnetic like iron.

and again rendered visible by the revolution of the eye-piece to the right or to the left. When the N. pole was nearest the observer, the rotation of the ray was right-handed; when the S. pole was nearest, it was left-handed. Common magnets acted in the same manner as electro-magnets, though more feebly.

(1121) The law of the action is this: "If a magnetic line of force be *going* from a *N.* pole, or *coming* from a *S.* pole, along the path of a polarized ray, coming to the observer it will rotate that ray to the right-hand." Thus, supposing Fig. 448 to represent a cylinder of glass, the line joining N and S is the magnetic line of force, and if a line be traced round the cylinder with arrow heads on it to represent direction, as in the figure, such a simple model held up before the eye will express the whole of the law, and give every position and consequence of direction resulting from it. The amount of rotation was in proportion to the extent of the diamagnetic through which the ray passed, and the power of the rotation was in proportion to the intensity of the magnetic force. The interposition of non-magnetic metals between the poles had no influence on the result; but iron, by diverting the direction of the lines of force, affected the results materially. That the phenomenon is directly connected with the magnetic form of force is proved by the circumstance, that the brightness of the polarized ray is developed *gradually*, the iron requiring some little time (a couple of seconds) to acquire its full magnetic intensity after throwing on the current.

Fig. 448.



(1122) All transparent bodies do not possess this power in the same degree, and some have it not at all; but in those in which it exists, whether solid or liquid, or however opposed in chemical character, the law of rotation is the same. The best substance is silico-borate of lead; both *flint* and *crown glass* give it, as do water, alcohol, ether, and, in fact, every liquid substance that has been tried; but Faraday was unable to find the power in rock crystal, Iceland spar, sulphate of baryta, carbonate of soda, or ice.

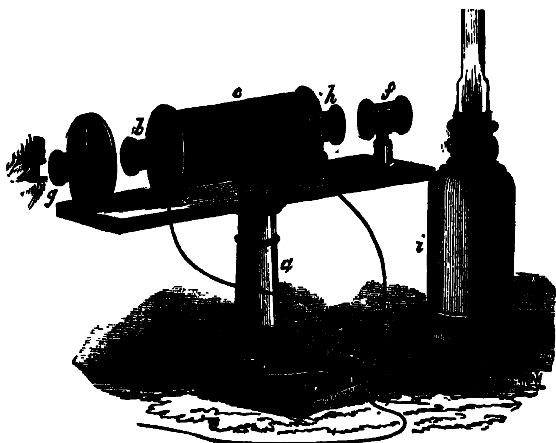
(1123) The following experiment is quoted by Faraday as clearly demonstrating that a ray of light may be electrified, and the electric forces illuminated. A tube was filled with distilled water and introduced as a core into a long helix or coil 65 inches long, and containing 1,240 feet of wire; it was placed in the line of the polarized ray, so that by examination through the eye-piece the image of the lamp-flame produced by the ray could be seen through it. Then the eye-piece was turned until the image of the flame disappeared, and afterwards the current of 10 pairs of plates was sent through the helix;

instantly the image of the flame reappeared, and continued as long as the electric current was passing through the helix; on stopping the current the image disappeared; the light did not rise gradually as in the case of electro-magnets, but instantly; when the current was sent round the helix in one direction, the rotation induced upon the ray of light was one way; when the current was changed, the direction of rotation changed likewise.

In this experiment the apparent deflection of the ray of light is by many believed to be occasioned by an alteration in the refracting power of the medium through which the ray passes, and not to an influence exerted directly by Magnetism on the beam of light.

(1124) The apparatus shown in Fig. 449, was constructed by Professor Böttger (*Beiträge zur Physik et Chemie Drittes Heft*, p. 1) for the illustration of these novel phenomena: *a* is a stand sup-

Fig. 449.



porting a pair of achromatic Nicol's prisms, *g* and *f*, placed horizontally; between these there is placed a brass tube, some 2 or 3 lines in diameter, and from 6 to 8 inches long, closed at both ends by plates of glass; *b h*, the tube, filled with any double refracting fluid, for instance, tartaric acid, oil of turpentine, a solution of sugar candy (⅓rd candy and ⅔rds water), &c., &c., is placed in the axis of a hollow helix, which is lined throughout its entire length with a thin cylinder of sheet iron, *c*; the projecting terminals of the helix are brought by means of the commutator, *d*, into connexion with the poles of a Grove's battery of 6 or 7 pairs. On letting the light of an argand lamp, *i*, pass through the hindermost Nicol's prism, and thus causing a ray of polarized light to traverse the saccharine

solution in *h b*, it will be observed that a certain position may be given to the front moveable prism, *g*, in which the field is dark; if, now, by completing the circuit, the galvanic current be caused to traverse the helix *c* in such a manner that it enters the right-handed helix, where the polarized ray enters the refracting liquid, the longitudinal magnetic axis coinciding with the axis of the ray, or in other words, the magnetic N. pole being at *b*, and the S. pole at *n*, there will instantly be indicated a rotation of the plane of polarization to the left, the field no longer remaining dark, but becoming of a reddish hue, the phenomenon remaining constant as long as the circuit is closed. On inverting the current by means of the commutator, so that the N. pole is brought to *h* and the S. pole to *b*, the plane of polarization becomes inverted to the right, the field at the same time becoming of a bluish green tint.

(1125) Taking the natural rotating force of a specimen of oil of turpentine as a standard of comparison, Faraday obtained the following numbers, a powerful electro-magnet being employed with a constant difference of 2½ inches between its poles:—

Oil of turpentine	11·8
Heavy glass	6·0
Flint glass	2·8
Rock salt	2·2
Water	1·0
Alcohol	less than water.
Ether	less than alcohol.

—the different substances being corrected by calculation to one standard length. That light and the magnetic and electric forces have a direct relation and dependence is further shown by the following experiment:* Place side by side a certain quantity of water in a helix, and a tube containing oil of turpentine. If the oil possesses right hand rotation, pass an electric current through the helix so as to give rotation to the right; the water in the tube will acquire a rotatory power to the right, and the two liquids will possess the same mode of action. Leaving now the tubes, the helix, and the current in the state just described, pass the polarized ray in the contrary direction through the tubes, and observe at the opposite extremity of the tube. The oil of turpentine will be still seen to turn the ray to the right, but it will not be the same with the *water*, which will turn the ray to the left; the rotation being absolutely connected with the direction of the electric current which moves in the circuit,

* Faraday, *Comptes Rendus*, January 16, 1846.

and which, seen through this extremity, passes to the left. If, instead of water, oil of turpentine be in the helix, and if the electric current be sufficiently intense to produce on the luminous ray a rotation equal to that determined by the oil, its rotatory power, observed on a ray passing in a certain direction, will appear double; while, examined by a ray passing in the contrary direction, it will be reduced to zero. It thus appears, that it is only through the intervention of matter that the direct relations of the magnetic force and light become manifest; that different matters possess the property in different degrees; and that as the substances between the magnetic poles, though clearly affected by the magnetic force, are not rendered magnetic in the sense of iron, their molecular condition, while in this state, must be *new*, and the force must be a *new magnetic force*.

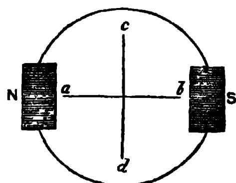
(1126) The rotatory power superinduced by magnetic action is quite independent of that which the substance possesses of itself. In oil of turpentine, for instance, whichever way a ray of light (polarized) passes through this fluid, it is rotated in the same manner, and rays passing in every possible direction through it *simultaneously* are all rotated with equal force, and according to one common law of direction, *i. e.*, all right handed, or else all to the left. This is not the case with the rotation superinduced on the same oil of turpentine by the magnetic or electric forces; it exists only in one direction, that is in a plane perpendicular to the magnetic line, and being limited to this plane, it can be changed in direction by a reversal of the direction of the inducing force. The direction of the rotation produced by the natural state is connected invariably with the direction of the ray of light, but the power to produce it appears to be possessed in every direction, and at all times, by the particles of the fluid; the direction of the rotation produced by the induced condition is connected invariably with the direction of the *magnetic line*, or the *electric current*, and the condition is possessed by the particles of matter, but strictly limited by the line or the currents changing and disappearing with it.

(1127) *The General Magnetic Condition of Matter.*—The first substance submitted by Faraday to the action of the magnetic forces was heavy silicated borate of lead glass. A bar of this substance, 2 inches long and ½ an inch wide and thick, was suspended centrally between the poles of a powerful electro-magnet; when the effect of torsion was over, the current was thrown on; the bar immediately moved, and took up a position *across the magnetic line of force* (equatorial).* On being displaced, it returned to it, and this happened

* Let N and S, Fig. 450, represent the poles of a horse-shoe magnet looking down

many times in succession. The reversal of the poles of the electro-magnet caused no difference. The bar went by the shortest course to the equatorial position. The power that urged the bar into this position was so thoroughly under command, that it could be either hastened in its course into it, or arrested as it was passing from it, by seasonable contacts at the voltaic battery. If the bar was in the direction of the axis, or *magnetic line of force*, it did not move on making battery contact, neither did it if it was originally in the equatorial position; but if it was in the least oblique, its obliquity increased till it became equatorial. Here, then, was a magnetic bar pointing E. and W. instead of N. and S.

Fig. 450.



(1128) If the bar was suspended nearer to one pole than the other, it was repelled from the nearer pole; and if it was equidistant from both poles, but in the *axial* line, that is in the line from pole to pole, it pointed *equatorially* on being moved a little on either side of the axial line from which it was apparently repelled. If two bars were suspended each near the opposite poles, both were *repelled* by their respective poles, and thus appeared to *attract* each other; so also when two bars were hung equatorially on either side of the axial line, both receded from that line, apparently repelling one another.

When a cube was employed, the effect was repulsion from both poles, and recession from the magnetic axis on either side. The tendency was to move from a *stronger* to a *weaker* place of magnetic force, and this is the cause of the pointing of any oblong arrangement. When one or two magnetic poles are active at once, the courses described by the glass form a series of curves, which Faraday calls *diamagnetic curves* in contradistinction to the lines called *magnetic curves*. In these experiments we have magnetic repulsion apparently without polarity.

(1129) A very great number of other substances, both solid and liquid, were then submitted to the action of the magnet, the liquids being enclosed in small glass tubes hermetically sealed. The results are given in the following table:—

upon them; the space between the poles is called "the magnetic field;" the line, *a b*, parallel to which a *magnetic* body, such as a bar of iron, would take up its position, is called the "axial line;" the line, *c d*, at right angles to *a b*, and parallel to which a *diamagnetic* body, such as a bar of bismuth would set, is called the "equatorial line."

POINTED EQUATORIALLY (DIAMAGNETIC).		POINTED AXIALLY (MAGNETIC).
Rock crystal.	Nitric acid.	Paper.
Sulphate of lime.	Sulphuric acid.	Sealing wax.
Sulphate of baryta.	Muriatic acid.	Fluor spar.
Sulphate of soda.	Solution of alkaline and earthy	Peroxide of lead.
Sulphate of potassa.		Plumbago.
Sulphate of magnesia.	salts.	China ink.
Alum.	Glass.	Berlin porcelain.
Muriate of ammonia.	Litharge.	Red lead.
Chloride of lead.	White arsenic.	Sulphate of zinc.
Chloride of sodium.	Iodine.	Shell lac.
Nitrate of potash.	Phosphorus.	Silkworm gut.
Carbonate of soda.	Sulphur.	Asbestos.
Iceland spar.	Resin.	Vermilion.
Oxalate of lead.	Spermaceti.	Tourmaline.
Tartrate of potash and	Caffeine.	Charcoal.
antimony.	Cinchona.	
Tartaric acid.	Margaric acid.	
Citric acid.	Wax from shell lac.	
Water.	Olive oil.	
Alcohol.	Oil of turpentine.	
Ether.	Jet.	
Sugar.	Caoutchouc.	
Starch.	Dried beef.	
Gum arabic.	Dried blood.	
Wood.	Fresh blood.	
Ivory.	Leather.	
Dried mutton.	Apple.	
Fresh beef.	Bread.	

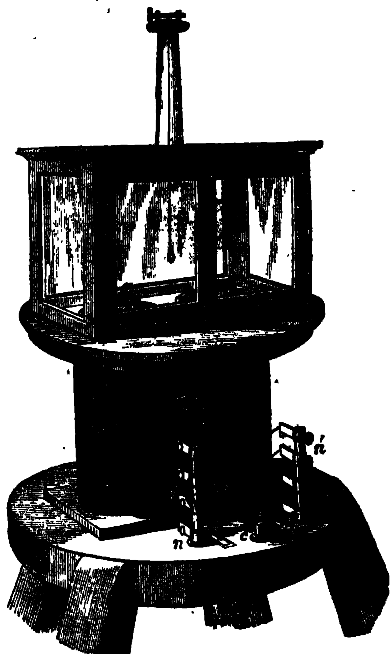
(1130) Phosphorus appears to stand at the head of all diamagnetic substances; its pointing could be verified between the poles of a common magnet. If a man could be suspended between the poles, he would point equatorially, for all the substances of which he is made possess this property. The reason why *blood* which contains iron is not magnetic, is, probably, because it is diamagnetic in a greater degree; and the latter force neutralizes and predominates over the former.

By these new facts, forces directly the opposite of those existing in magnetic bodies are proved to have an existence; for, whereas the latter produce *attraction*, the former produce *repulsion*. The former

cause a body to set in the *axial* direction, but the latter make it take an equatorial position.

(1131) *Action of Magnets on the Metals.*—The metals were examined as to Magnetism by suspending them in pieces of about 2 inches long in the magnetic field of the electro-magnet. The apparatus employed by M. Plücker (a philosopher who has followed up these inquiries with great ability and success) is shown in Fig. 451. The electro-magnet *a b* is surrounded with 4 coils of thick silk-covered copper wire, each wound separately around its 2 branches, and communicating with 2 metallic conductors *n n'*. The current from the battery is thrown on and off, and changed in direction, by means of a commutator *c*. The poles of the magnet are surmounted by a glass case with a suspension thread, so that different substances may be submitted to the action of the magnet in a still atmosphere, or in atmospheres more or less charged with various vapours and gases.

Fig. 451.



(1132) The following metals, when thus tried, were either not magnetic, or if so, to so small an amount as not to destroy the results of the other force:—

Antimony.	Bismuth.	Cadmium.	Copper.
Gold.	Lead.	Mercury.	Silver.
Tin.	Zinc.		

The following were magnetic in the sense of iron:—

Cobalt. Nickel. Platinum. Titanium. Palladium.

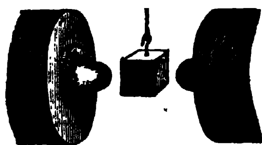
Of all the metals, *bismuth* was found to be the most eminently diamagnetic, excelling in this property even heavy glass and phosphorus; and it is, therefore, specially adapted for showing the various phenomena. Its movements were, however, complicated, and demanded careful analysis; but they all resolved themselves into their

simple elementary origin; the ruling principle being that each particle of the metal tends to go from the *stronger* to the *weaker* points of the magnetic field. When bismuth powder was sprinkled upon paper and laid over the horizontal circular termination of the vertical pole of a bar electro-magnet, it retreated in both directions, inwards and outwards, from a circular line just over the edge of the core, leaving the circle clear, and at the same time showing the tendency of the particles of bismuth to move in all directions from that line; and when the pole was terminated by a *cone*, a clear line could be traced through the powder, by drawing the paper on which it was sprinkled over the cone.

(1133) Copper (in consequence, as Faraday believes, of its excellent conducting power for electric currents) exhibited some remarkable phenomena. When suspended between the poles it first advanced towards the axial line, as if it were magnetic; it then suddenly stopped, and took up a new position, from which it could only be removed by the application of some force. Even when swinging with considerable momentum, it could be caught up and retained at will. If after the Magnetism had been sustained for two or three seconds the electric current was suddenly stopped, there was instantly a strong action on the bar, and it began to revolve; on again renewing the current it was again arrested as before. Some other metals, viz., silver, gold, zinc, cadmium, tin, mercury, platinum, palladium, lead, and antimony exhibited in a greater or smaller degree the same phenomena.

In order to form a sufficient idea of the arresting power of these induced currents, take a lump of solid copper, approaching to the cubical or globular form, weighing from a ¼ to ½ a pound, suspend it by a long thread, give it rapid rotation, and then introduce it, while spinning, into the magnetic field of the electro-magnet,—its motion will be instantly stopped, and on trying further to spin it whilst in the field it will be found impossible.

Fig. 452.



(1134) Faraday next submitted various metallic salts to the action of the magnet: all salts and compounds containing iron in the *basic part* were found to be magnetic both in the form of crystals and when in solution; yellow and red prussiate of potash were however both diamagnetic; pure sulphate and chloride of nickel, both in crystals and in solution, were magnetic; oxide of titanium, oxide of chromium, and chromic acid were magnetic, as were also

the salts of manganese and chromium; the compounds of lead, platinum, palladium, and arsenic pointed equatorially, as was also the case with chromate of potash. An interesting set of results was obtained by filling tubes with ferruginous solutions of different degrees of strength, and suspending them in similar ferruginous solutions, also of different degrees of strength, between the poles of the electro-magnet. When the solution in the tube was stronger, or contained more iron than that in the glass in which it was suspended, it pointed *axially;* when it was weaker, or contained less iron than that in the glass, it pointed *equatorially;* and when the solutions in both tube and glass were of the same degree of strength, the tube was indifferent. Let *n*, Figs. 453 and 454, represent a thin

Fig. 453.

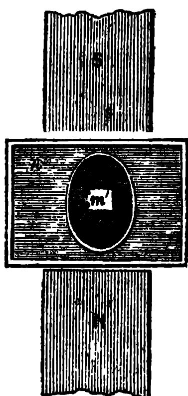
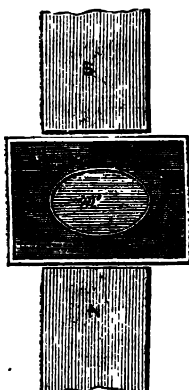


Fig 454.



glass trough, filled with a solution of 16 grains of crystallized proto-sulphate of iron in each cubic inch of water, the trough being placed between the poles of a powerful magnet; let *m′* be an oblong glass trough, containing a solution of 8 grains of protosulphate of iron to each cubic inch of water, the latter will set *across* the magnetic field as in Fig. 454, like a bar of bismuth, because it contains less iron than the liquid in which it is suspended. Let the exterior trough be filled with the weaker solution, and the interior tube with the stronger, the latter will now set as shown in Fig. 453, that is, axially, as it would do in air. Iron and nickel, when heated to a degree far above that required to render them insensible to an ordinary magnet, still pointed axially between the poles. By multiplying these experiments the following *order* of metals in their relation to the magnetic force was obtained (0° is the medium point or condition of a metal or substance indifferent to the magnetic force):—

MAGNETIC.	DIAMAGNETIC.
Iron.	Bismuth.
Nickel.	Antimony.
Cobalt.	Zinc.
Manganese.	Tin.
Chromium.	Cadmium.
Cerium.	Sodium.
Titanium.	Mercury.
Palladium.	Lead.
Platinum.	Silver.
Osmium.	Copper.
	Gold.
	Arsenic.
	Uranium.
	Rhodium.
	Iridium.
	Tungsten.

0°.

(1135) *Action of Magnets on Air and Gases.*— Common air, sealed hermetically in a glass tube, and placed between the poles. pointed feebly towards the equatorial position, the effect being due to the glass. When the air round the tube was rarefied, and finally exhausted as far as possible by a good pump, not the slightest difference in the pointing of the tube could be observed, neither could there when the tube was surrounded with hydrogen or carbonic acid; there seems, therefore, no difference between dense air and rare air, or between one gas and another. On the other hand, the air tube pointed axially when subjected to the magnetic forces whilst submerged in water, alcohol, turpentine, and mercury; the action of the air in the fluids being the same as the action of a magnetic body in air. Various gases and vapours and a vacuum pointed *equatorially* when surrounded with air, but *axially* when surrounded with liquids; the equatorial pointing being due to the glass only, but the axial pointing depends upon the relation of the contents of the tube to the surrounding air. It appears, therefore, that gases and vapours occupy a medium position between magnetic and diamagnetic bodies; and that however marked the diamagnetic character of a body may be, it loses all traces of this character when it becomes vaporous. Taking air and a vacuum as the neutral point, the following table represents a general list of certain substances in their relation to the magnetic force: —

Iron.		Bismuth.
Nickel.		Phosphorus.
Cobalt.		Antimony.
Manganese.		Heavy glass.
Palladium.		Flint glass.
Crown glass.	Air and vacuum.	Mercury.
Platinum.	0°.	Water.
Osmium.	Middle of the series.	Gold.
		Alcohol.
		Ether.
		Arsenic.

(1136) This position, intermediate between magnetic and diamagnetic bodies taken by air; its exhibiting no change in its relations by rarefaction; its taking a place exactly in the middle of a great series; and lastly, the fact that all gases and vapours are alike, seems to point to the fact that air must have a great, and perhaps an active part to play in the physical and terrestrial arrangement of magnetic forces. The whole of these extraordinary discoveries prove that the magnetic force presides over matter as universally as the gravitating, the electric, the chemical, and the cohesive forces, and that substances arrange themselves into two great divisions, the *magnetic* and the *diamagnetic*, which are in the same general *antithetical* relation to each other as *positive* and *negative* in Electricity, or as *northness* and *southness* in polarity, or as the lines of electric and magnetic forces in magnetic Electricity. Neither was this remarkable power (the diamagnetic), given to bodies for nothing. "It doubtless," says Faraday, "has its appointed office, and that, one, which relates to the whole mass of the globe. For, though the amount of the power appears to be feeble, yet, when it is considered that the crust of the earth is composed of substances of which by far the greater portion belongs to the *diamagnetic* class, it must not be too hastily assumed that their effect is entirely overruled by the action of the magnetic matters, whilst the great mass of waters and the atmosphere must exert their diamagnetic action uncontrolled." Faraday found that it required more than 48·6 grains of crystallized protosulphate of iron to neutralize the diamagnetic power of 10 cubic inches of water, and it is not, therefore, at all unlikely that many of the masses which form the crust of our globe may have an excess of diamagnetic matter and act accordingly. He throws out the notion that it may not hereafter prove impossible to construct an instrument for measuring one of the conditions of terrestrial Magnetism, on the principle that a pound of bismuth or of

water estimated at the equator, where the magnetic needle does not dip, ought theoretically to weigh *less* than in latitudes where the dip is considerable, whilst a pound of *iron* or *nickel* ought under the same change of circumstances to weigh more.

(1137) *The Magne-crystallic Force.*—In his experiments on bismuth, Faraday had noticed some very embarrassing results: *e. g.*, taking at random from a quantity 4 small cast cylinders of the metal, and suspending them horizontally between the poles of the electro-magnet, the first pointed *axially*; the second, *equatorially*; the third, *equatorial* in one position, and *obliquely equatorial* if turned round on its axis 50° or 60°; the fourth, *equatorially and axially* under the same treatment; whilst all of them were repelled by a single magnetic pole, thus showing their strong and well-marked diamagnetic character. The cause of these variations he succeeded in tracing to the regularly crystalline condition of the metallic cylinders. On suspending between the poles a carefully selected group of crystals of bismuth, and sending the current on, the metal vibrated strongly about a given line, into which at last it settled; and if moved out of that position, it returned when at liberty into it, pointing with considerable force, with its greatest length *axial*. The position taken up by the metal had nothing to do with its shape, but was entirely dependent on its crystalline condition, and the effect occurred with a single pole. Now, bismuth being eminently a diamagnetic body, and as such tending to pass from a stronger to a weaker place of magnetic force, it would have no tendency to point at all in a field of uniform force (such as between the rounded poles of an electro-magnet); the crystalline group, however, *does* point in such a field, the tendency being that the line joining two opposite solid angles of the crystalline group, should take up an *axial* position. The impelling force is therefore distinct, both from the magnetic and the diamagnetic, and is called by Faraday the *magne-crystallic force.*

(1138) It was further noticed that the *cleavage* of the bismuth was not made with equal facility at the four solid angles, and that *two*, or more frequently *one* of the planes produced by cleavage were brighter and more perfect than the others. When the crystal was suspended in the magnetic field with its bright plane *vertical*, it pointed with considerable force with the plane towards either the one or the other magnetic pole, so that the magne-crystallic axis appeared now to be *horizontal*, and acting with its greatest power; when, however, the crystal was suspended with its bright plane *horizontal*, so that the magne-crystallic axis was *vertical*, it did not point at all; the law of action appearing to be, "that the line or axis of magne-crystallic force tends to place itself parallel, or as a tangent to the

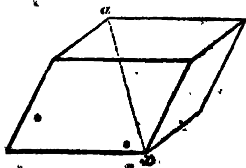
magnetic curve or line of magnetic force, passing through the place where the crystal is situated." It does not require very powerful magnets to exhibit these remarkable phenomena; they may be verified with common horseshoes, with a lifting power of under 2 pounds. Neither is bismuth the only metal in which they are observed; Faraday having succeeded in obtaining magne-crystallic action with antimony, arsenic, zinc, titanium, and with the sulphates of nickel and iron.

(1139) The most remarkable property of this force is its not possessing a dual or *antithetical* character, *both* poles of the crystal having like characters; but Faraday has shown by the following experiment that a crystal of bismuth is able to re-act upon and affect a magnet *at a distance*. He suspended a small magnetic needle perpendicularly by a single cocoon filament, and placed near its lower pole a crystal of bismuth with the *magne-crystallic axis* in a horizontal direction, the whole being left for two or three hours; the effect was small but distinct, the result being, that if the direction of the magne-crystallic axis made an angle of 10°, 20°, or 30°, with the line from the magnetic pole to the middle of the bismuth crystal, *then the pole followed it*, tending to bring the two lines into parallelism, and this it did whichever end of the magne-crystallic axis was towards the pole, or whichever side it was inclined to. It thus appears that a crystal of bismuth is able to react upon and affect a magnet at a distance. This new force Faraday believes to be one *induced* under the magnetic and electric influences, and not an original force inherent in the crystal; for the crystal can take away nothing from the magnetic fluid, neither is it affected by the earth's Magnetism; it is, however, a most peculiar one, the body possessing it being moved without having any attractive or repulsive powers.

(1140) Whilst engaged in the study of the diamagnetic properties of organic bodies, Plücker was induced to submit various crystalline bodies to the action of the magnet, and he made the following remarkable discoveries Taylor's "Scientific Memoirs," vol. 5): "When any crystal having a single optic axis* is placed between the

* In all crystals which possess the property of double refraction, there are *one* or *two* directions in which the splitting of the ray does not take place; these directions are called the *axes* or the *optic axes* of the crystals. Those crystals, the interiors of which present only one direction of indivisibility, are called *uniaxial*; those with two directions of indivisibility are called *binaxial*. As an example of an uniaxial crystal, Iceland spar may be taken, the primitive form of which is a rhombohedron (Fig. 455), that is, a crystal of this substance, whatever its form may

Fig. 455.



two poles of a magnet, this axis is *repelled* by each of the two poles. If the crystal has two optic axes, each of these two axes is repelled by each of the two poles with the same force. The force which produces this repulsion is independent of the magnetic or diamagnetic condition of the mass of the crystal; it diminishes *less* as the distance from the poles of the magnet increases, than the magnetic or diamagnetic forces emanating from these poles and acting upon the crystal. M. Plücker suspended a green plate of

be, is to be regarded as made up of an infinite number of molecules symmetrically arranged side by side, each being a rhombohedron. The line *a x* joining the obtuse summits of one of these rhombohedrons is called its *crystallographic axis.* It has been proved experimentally to be a law without exception that in an *uniaxial* crystal, the axis of double refraction, or the *optic axis, coincides* with the *crystallographic axis.* It has further been found that in some crystals the ray of extraordinary refraction is inclined *from* the axis, and in others *towards* it, more than the ordinary ray. The former are said to have a *negative* axis, the latter a *positive.* Uniaxial crystals may, therefore, be arranged in two classes, as in the following table (Pouillet's "Elements of Physics"):

NEGATIVE UNIAXIAL CRYSTALS.

Iceland spar.	Beryl
Carbonate of lime and magnesia.	Apatite.
Carbonate of lime and iron.	Idocrase (Vesuvian).
Tourmaline.	Wernerite.
Rubellite.	Mica (certain varieties).
Corindon.	Phosphate of lead.
Sapphire.	Arseniophosphate of lead.
Ruby.	Hydrate of strontia.
Emerald.	Arseniate of potash.
Hydrochlorate of lime.	Octohedrite.
Hydrochlorate of strontia.	Prussiate of potash.
Subphosphate of potash.	Phosphate of lime.
Sulphate of nickel and copper.	Arseniate of lead.
Cinnabar.	Arseniate of copper.
Mellite.	Nephiline.
Molybdate of lead.	

POSITIVE UNIAXIAL CRYSTALS.

Zircon.	Sulphate of potash and iron.
Quartz.	Subacetate of copper and lime.
Oxide of iron.	Hydrate of magnesia.
Tungstate of zinc.	Ice.
Stannite.	Hyposulphate of lime.
Boracite.	Dioptase.
Apophylite.	Red silver.

It was discovered by Fresnel that in binaxial crystals there is no *ordinary* ray properly so called; neither of the rays into which the light becomes resolved obeying the usual law of refraction or the *law of sines,* as it is termed (the sines of the angles of incidence and refraction *not* being in a constant ratio.) The following table (Brewster) contains the names of a few binaxial crystals with the inclination of their optic axes to each other.

tourmaline, the longitudinal direction of which corresponded with the direction of its optic axis, between the poles of an electro-magnet in the apparatus shown in Fig. 451, in such a manner that the direction of the thread corresponded with the direction of the optic axis; the plate being magnetic, arranged itself between the poles, the direction of its breadth coinciding with a straight line connecting the poles, as any other magnetic body of the same form would have done. But when the plate was suspended in such a manner that the direction of its *breadth* coincided with that of the silk thread, so that the optic axis could now oscillate freely in a horizontal plane, it assumed that position which a *diamagnetic* body of the same form would have done: i. e., with its axial and longitudinal direction perpendicular to the line of the apices of the poles. On again suspending the plate so that it could oscillate horizontally, it took up the same position as a diamagnetic body of the same form would have done. The direction of its breadth being in the line of the apices of the poles, and its longitudinal and axial direction perpendicular to it. By opening and closing the circuit in each of the three positions of suspension, the tourmaline could be turned round and retained in exactly the opposite position.'

(1141) Plücker then took a dark brown crystal, having the form of a six-sided prism, and suspended it between the poles, the latter being so close together that the crystal had just room to oscillate freely. Under these circumstances, the magnetic attraction caused

A, Principal Axis,—Positive.		B, Principal Axis,—Negative.	
Substances.	Inclination.	Substances.	Inclination
Sulphate of nickel	3° to 42° 1′	Nitrate of potash.	5° 20′
Biborate of soda	28° 42′	Carbonate of strontia	6 56
Sulphate of baryta	37 42	Talc	7 24
Spermaceti	37 40	Carbonate of lead	10 35
Henlandite	41 40	Mica (certain varieties)	14 0
Sulphate of soda and magnesia	46 49	Sulphate of magnesia	37 24
Brazilian topaz	49 50	Carbonate of ammonia	43 24
Sulphate of strontia	50 0	Sulphate of zinc	44 28
Sulphate of lime	60 0	Sugar	50 0
Nitrate of silver	62 16	Phosphate of soda	55 20
Scottish topaz	65 0	Tartrate of potash	71 20
Sulphate of potash	67 0	Tartaric acid	79 0
Potassiotartrate of soda	80 0		

Uniaxial crystals include all those crystals belonging to the pyramidal and rhombohedral systems; *binaxial* crystals include those belonging to the prismatic oblique, and anorthic systems.

the tourmaline to assume such a position that the axis of the prism, which is also its optic axis, coincided with the line of the apices of the poles. The poles were then gradually separated from each other, and as they receded, the force tending to keep the crystal in its first position became less and less intense, and when their distance amounted to 80 millimetres (about $\frac{3}{10}$ths of an inch), the crystal rotated 90°, as if it became diamagnetic, so that its axis was now perpendicular to the line of the apices of the poles. On the further separation of the latter, the force which retained it in the position just described increased, and in this, it continued distinctly to remain after the apices of the poles had been entirely removed. At a sufficient distance from the poles, therefore, the repulsive action overcomes the magnetic attraction.

(1142) A crystal of calcareous spar, a decidedly diamagnetic body, was then suspended between the poles, so that its axis should oscillate horizontally. On charging the magnet, the *axis* became placed exactly *equatorially*, the crystal assuming a position in which neither a magnetic nor a diamagnetic mass of the same form would have rested when acted upon by the magnetic and diamagnetic action of the poles of the electro-magnet. Various other magnetic crystals, viz., rock crystal, opaque crystallized quartz, a square octohedron of zircon, two yellowish-green transparent crystals of emerald, a black idocrase, and a large corundum, exhibited the same deportment, as did also the following *binaxial* crystals (crystals having two optic axes), mica, a magnetic body; topaz, sugar, arragonite, nitre, and sulphate of soda—diamagnetic bodies. All these, when suspended so that the planes of their two optic axes could oscillate horizontally, took up the equatorial position.

(1143) These experiments appeared to Plücker to disclose a relation between the forms of the ultimate particles of matter and the magnetic forces, and to lead to the remarkable result that we can determine crystalline forms by the magnet. He thought, moreover, that they showed the existence of a relation between the forces which are in action during crystallization and the magnetic forces. According to Faraday's view, the new force discovered by Plücker is an *optic axis* force exerted in the equatorial direction, and therefore existing in a direction at right angles to that which produces the magneto-crystallic phenomena; both forces, however, have relation to the force conferring the condition of crystalline structure, and Faraday is of opinion that they have one common origin and cause.

(1144) The more recent experiments of Tyndall and Knoblauch (*Phil. Mag.*, vol. xxxvi. p. 178, and vol. i., N. S., p. 1) lead, however, to a different view of the matter. These physicists have investigated

Plücker's phenomena with great ability. They have shown that the action of a crystal so far from being independent of the Magnetism or Diamagnetism of its mass, as announced by Plücker, is totally changed by the substitution of a magnetic constituent for a diamagnetic. In determining whether the optic axis will be repelled or not, their plan was to take a thin rhomb, cloven from the crystal, and having ground it into the shape of a disc, it was suspended between the poles, when, if it belonged to a class whose optical axis is repelled, the line bisecting the acute angles of the rhomb set itself axial, if of the other class, the same line set itself equatorial. Their method of examining crystals was to pound them in an agate mortar, and then to make them into a paste with distilled water, which, when dry, they suspended between the poles. On experimenting with gutta percha, Messrs. Tyndall and Knoblauch found that a circular disc of this substance always arranged itself with the direction of the fibre *axial*, and a parallelogram, ¾ths of an inch long and ½ an inch wide, with the fibres crossing it transversely, set stiffly *equatorial*. This they consider to be owing to the facility with which the magnetic force can act in the direction of the fibre. The same phenomena were produced with ivory, which could be made to stand either axially or equatorially by cutting it in a particular way. They consider that Plücker's explanation of Faraday's experiment is incorrect, and that the *setting* of a crystal in the magnetic field is dependent on the amount of magnetic or diamagnetic force in the direction of the lines of cleavages.

(1145) The experiments of Messrs. Tyndall and Knoblauch are irreconcilable with Plücker's statement, that the position of the optic axis is independent of the Magnetism or Diamagnetism of the crystal; nor does their extensive examination of crystalline bodies confirm the law announced by the German philosopher, that "there will be either repulsion or attraction of the optic axes by the poles of the magnet, according to the crystalline structure of the crystal—if the crystal is a *negative one* there will be repulsion, if it is a positive one there will be attraction;" in some cases they found this law to hold good, but in many others the results were opposed to it.

(1146) Messrs. Tyndall and Knoblauch quote the following experiment to show that the deportment of crystalline bodies in the magnetic field may be explained without assuming the existence of an "optic axis" force: Take a slice of apple, rather thicker than a penny piece, stick through it, in a direction perpendicular to its flat surface, some bits of iron wire, and hang it in the magnetic field; it will set itself *equatorial, not by repulsion*, but by the attraction of the iron wires. Substitute bits of bismuth wire for the iron, the

apple will now set *axial, not by attraction*, but by the repulsion of the bismuth. Now, arrangement is conceivable amongst the particles of a magnetic or a diamagnetic body capable of producing similar effects, and if the magnetic and diamagnetic forces be associated with the particles of matter, the inference is not unreasonable that the closer these particles are aggregated, the less will be the obstruction offered to the transmission of the respective forces among them. As regards Magnetism, different directions through the same body may represent good and bad conductors in Electricity, the line of preference being that of closest contact among the material particles. If some fine bismuth powder be kneaded into a paste with gum-water, and then made into a roll, about 1¼ inch across, it will point *equatorially* between the magnetic poles, but if it be squeezed flat it will point *axially*, even though its length be ten times that of its breadth; again, if a similar roll be made of pounded carbonate of iron, it will point *axially*, but after being squeezed, it will recoil violently between the poles, and point *equatorially*. The cause of these phenomena is evident. The line of closest contact is perpendicular in each case to the surface of the plate, a consequence of the pressure in this direction; and this perpendicular stands axial or equatorial, according as the plate is magnetic or diamagnetic. This sort of action must exist in all non-homogeneous masses, and there must be an election of a certain line by the force operating, and this line they call *the line of elective polarity*.

(1147) Messrs. Tyndall and Knoblauch imitated Faraday's experiments with crystals of sulphate of iron by substituting for them a model of powdered carbonate of iron with gum-water, made into a paste, and compressed and arranged so that the line of "elective polarity" through the model was perpendicular to the length. With this they obtained corresponding results; the model, though magnetic, and strongly attracted by the magnet, actually receded from it when made to stand between the flat-faced poles obliquely. In the same way, by using bismuth powder, they imitated Faraday's experiments with a plate of bismuth. Now, as by reducing the substances to powder, all symmetry of crystalline arrangement is annihilated, and the force among the particles which makes them cohere in regular order, rendered ineffective, it would seem that Magnetism and Diamagnetism are clearly modified by mechanical arrangement. They enunciate the general principle in the following terms: "*If the arrangement of the component particles of any body, be such as to present different degrees of proximity in different directions, then the line of closest proximity, other circumstances being*

equal, will be that chosen by the respective forces for the exhibition of their greatest energy. If the mass be magnetic, this line will stand axial; if diamagnetic, equatorial." Both experiment and speculation seem, indeed, to concur in pronouncing the line of closest proximity among the particles to be that in which the magnetic and diamagnetic forces will exhibit themselves with peculiar energy, thus determining the position of the crystalline mass between the poles.

(1148) It had been announced by Plücker as a law that the magnetic attraction decreases in a quicker ratio than the repulsion of the *optic axis*. By this law he accounted for the following fact. On setting a small rhomboid of Iceland spar, with its optic axis horizontal, between the pointed poles, brought together as closely as possible, it sets equatorially, the optic axis coinciding with the magnetic axis; on now separating the poles ¼ or ⅜ of an inch from each other, the rhomboid turns through 90°, and sets with its optic axis equatorial, and its greatest length axial. In the first instance the diamagnetic force overcame the optic axis force; in the second the optic axis force was the strongest. Tyndall and Knoblauch imitated these phenomena exactly with a *model* rhomboid, made by dissolving pure Iceland spar in hydrochloric acid, precipitating by carbonate of ammonia, and making with this precipitate a dough with gum-water, which they squeezed in one direction, so that the line of compression through the model coincided with that which represented the optical axis. Between the *near* points of the magnet the artificial optical axis stood from point to point; between the *distant* points it stood equatorially. They also constructed models of magnetic crystals from emery sand-paper; some of these, where magnetic layers of emery were perpendicular to its length, acted in the magnetic field precisely like a *prism of beryl;* between the near points both stood axial, between the distant points equatorial. From these and many similar experiments, these intelligent philosophers came to the conclusion that both classes of phenomena have a common origin; and that from the deportment of crystalline bodies between the poles of a magnet, no direct connexion between light and Magnetism can be inferred.

(1149) *Constancy of Differential Magne-Crystallic Force in Different Media.*—It had been observed by Faraday in his earlier experiments on *magne-crystallic* action, that with respect to bismuth the relation between the magnetic force in the axial and equatorial directions was unchanged by varying the surrounding medium from water to a solution of sulphate of iron. In his Thirtieth Series of Experimental Researches (Nov. 15th and 25th, 1855), he makes this condition the subject of further and special investigation. The

method employed to compare the possible variation of force produced by different circumstances, was to suspend the magne-crystal by a torsion fibre or wire, to place it in the magnetic field, to adjust the torsion index so that it should be at zero when the crystal had taken its position of stable equilibrium; then to put on *right-handed* torsion until the crystal had attained the point of unstable equilibrium, or the upsetting point on that side; and after having noticed the torsion required, to reverse the motion, and put on *left-handed* force, until the upsetting point on the opposite side was attained. Either of these forces, *minus* the deflection, is the measure of the upsetting force, and therefore the sum of these two observations, *minus* the number of degrees through which the crystal has moved in passing from one upsetting point to the other, may be considered as expressing the force which solicits the crystal to retain its stable position of rest.

(1150) The magnet employed was that great one constructed by Logeman, and sent to the Exhibition of 1851. It could sustain a weight of 430 pounds, and is very constant in power. The sliding poles pieces were of square iron, and presented either pointed terminations towards each other, or two flat faces 1·7-inch square, which could be brought up to the opposite sides of the troughs or vessels containing the different fluids or media required for the experiments. These vessels were of various sizes and kinds; but the outer ones were usually of copper, with flat sides, that the pole pieces might bear against them, and be thus preserved in their position during the progress of a single experiment, or a series of comparative results. The torsion suspender was about 24·5 inches in length, and was either a fine platinum wire, of which 28·5 inches weighed 1 grain, or a finer wire of silver, or a bundle of cocoon silk fibres. The torsion wire terminated below, by a hook, made out of a flat piece of copper foil, intended to receive on its edge a corresponding hook attached to the object submitted to experiment. The crystal was held by one turn of a fine copper wire which was continued upward for 5·7 inches, and terminated by a flat hook, like that just described. A horizontal bristle was fixed to each loop, and this, by its position, not only showed the place of the crystal beneath, but being retained between moveable stops associated with a horizontal scale, it indicated when the crystal was approaching the upsetting point, and being held within, and governed by the stops, allowed them, through it, to govern the crystal. The balance was enclosed by glass, to obviate the effects of currents of air.

(1151) With this apparatus Faraday experimented with *bismuth, tourmaline, protocarbonate of iron,* and *red ferroprussiate of potassa,*

in various media. With a bismuth crystal, in the form of an octagonal prism, suspended perpendicularly between the flat faces of the sliding poles, so that its magne-crystallic axis was horizontal, the upsetting torsion force in *air* was 2250°; in *absolute alcohol*, 2269°; in *water*, 2230°; and in saturated solution of *protosulphate of iron*, 2234°. In another experiment at a higher temperature, viz., 160° Fahr., the torsion force in water was 1945°, and in melted *phosphorus*, 1950°. With tourmaline the following numbers were obtained, the fine silver torsion wire being employed: *water*, 1082°; *olive oil*, 1085°; *alcohol*, 1081°; *air*, 1079°; saturated solution of *protosulphate of iron*, 1081°. A rough octagonal prism of native *protocarbonate of iron* (a highly paramagnetic substance) being suspended between the poles, opened to the full extent of the magnet, viz., 4·7 inches; the torsion force in *water* was 542; in *air*, 543; and in *protosulphate of iron*, 542. Lastly, a crystal of *red ferroprussiate of potash*, gave a torsion force in *air*, 314; and in *camphine*, 316.

(1152) These results point to the conclusion that there is no experimental difference in the proportion of the force developed in different directions in a magne-crystal, by the action of induction, whatever be the nature of the medium surrounding it, and whatever the difference in the paramagnetic and diamagnetic character of the crystals, or the media employed,—crystals differing as much as bismuth and carbonate of iron, and media differing as greatly as phosphorus and saturated solution of protosulphate of iron having been employed. The aptitude of a magne-crystal, when in the magnetic field, to assume a maximum conductive state in a given direction, makes it similar in action to a permanently magnetized sphere; and magne-crystals may be employed in experiments to measure magnetic force just as needles are; indeed, they are in some points of view philosophically more accurate, being equal in quality in all their parts, taking up precisely the same state under the same inductive force; having no coercitive or retentive faculty, and being independent of the surrounding medium.

(1153) As the setting force of a crystal remains constant for any surrounding medium, the possibility existed of finding a magne-crystal and a medium so related that the attraction and repulsion of the crystal as a whole, should be convertible terms depending upon the position of the crystal in regard to the lines of force. This case Faraday realized with the paramagnetic red ferroprussiate of potassa and a solution of sulphate of iron, and also with the diamagnetic crystal, carbonate of lime, and diluted alcohol. He also sought for a crystal amongst the ferrocarbonates of lime having this relation to

the assumed natural zero presented by a vacuum, or carbonic acid; but this case was not realized.

(1154) *Action of Heat on Magne-crystals.*—When magne-crystals subjected to the same constant magnetic force, were raised or lowered to different temperatures, it was found that the setting force was affected; and at all temperatures, from 0° Fahr. upwards, the force diminished as the temperature became higher. Thus the torsion force of a crystal of bismuth at 92° being 175°, was at 279° diminished to 82°; that of a tourmaline, by passing from the temperature of 79° to 289°, was so far diminished, that the power at the lower temperature was nearly double that at the higher. A like result occurred with carbonate of iron, and also with compressed bismuth. In all these cases the bodies resumed their first full power on returning to lower temperatures, nor was there any appearance of magnetic *charge* in any part of the range of observations. Between 32° and 300° the force of bismuth appeared to alter by equal, regular degrees; but with tourmaline and carbonate of iron the change was greatest for an equal number of degrees at the lower temperatures. At a full red heat, however, both tourmaline and calcareous spar retained a portion of their magne-crystallic force or condition, and so did carbonate of iron up to that temperature at which it was decomposed. A crystal of ferrocarbonate of lime had its magnetic condition absolutely reversed by change of temperature; at low temperatures the optic axis pointed axially, and at high temperatures equatorially.

(1155) *Effect of Heat upon the Absolute Magnetic Force of Bodies.*—At temperatures varying from 30° to 288° the inductive force in *iron* appears to undergo no change, having obtained and kept its maximum degree; with *nickel* there is a diminution of force at the upper temperature, which is in accordance with the general effect of heat; with *cobalt*, on the other hand, there was an *increase* of power with elevation of temperature. Faraday thinks it probable that in passing to lower temperatures than those employed, a particular temperature would be arrived at for nickel and iron, presenting the maximum magnetic induction for each, and below which their inductive force would diminish—a view which adds much additional interest to the relation between heat and Magnetism.

(1156) *Diamagnetic Polarity.*—By the following experiment, Weber (*Pogg. Ann.* Jan., 1848) considers the polarity of bismuth to be proved: A strong horseshoe magnet is laid upon a table in such a position that the line joining its two poles is perpendicular to the magnetic meridian, and to be considered as prolonged on one side; in that line, and near the magnet, is to be placed a small

powerful magnetic needle, suspended by a cocoon silk, and on the other side of it, the pole of a bar magnet, in such a position, and so near, as exactly to counteract the effect of the horseshoe magnet, and leave the needle to point exactly as if both magnets were away. Then a mass of bismuth being placed between the poles is said to react upon the small magnet needle, causing its deflection in a particular direction, and is supposed to indicate the polarity of the bismuth under the circumstances, as it had no such action when the magnets were away. A piece of iron, in the place of the bismuth, produces a contrary deflection of the needle. This experiment may be variously modified, but in every case the force of the bismuth must be observed upon other magnet poles than those which determine the diamagnetic condition of the bismuth, and they all concur (according to Weber) in confirming the assertion that bismuth constantly acts upon such poles in an opposite manner to iron in its place, that it consequently repels where iron attracts, and attracts where iron repels; in short, that at other magnet poles than those which diamagnetize the bismuth we as frequently observe attractive as repulsive forces of the bismuth.

(1157) In order to remove every doubt as to the diamagnetic force being really nothing else than the magnetic fluids, or their equivalents Ampère's currents, Weber proceeded to examine whether, agreeably with the laws of induction discovered by Faraday, an electric current can be induced in a neighbouring conductor by rotating a diamagnetic body under the influence of a powerful magnet. The following was the arrangement adopted: An iron nucleus, 600 millimetres * in length, coated several times with thick copper wire, was used as the electro-magnet. To the circular terminal surface, 50 millimetres in diameter, of this iron nucleus, was fixed the annular conductor, which consisted of copper wire, 300 metres long, and ⅔rds of a millimetre thick, well spun with silk, and coiled upon wooden cylinders. The space included in this annular conductor, in which the bar of bismuth was to be placed, was 140 millimetres in length, and 15 millimetres in breadth; the bar of pure precipitated bismuth was somewhat thinner. The extremities of the annular conductor were connected with a commutator, as were also the extremities of the multiplier of a very sensitive galvanometer, the magnet needle of which was provided with a mirror, in which the image of the distant scale was observed by a telescope directed towards it. The galvanometer was, moreover, provided with so effective a damper that it was scarcely possible to observe any vibration of the needle.

* 1 millimetre = 0·03937 English inch; 1 metre = 39·37 English inches.

Now, whilst a very powerful and constant galvanic current passed through the thick wire of the electro-magnet, the bar of bismuth was withdrawn from the annular conductor, the commutator changed, and the bar of bismuth again inserted, the commutator again changed, and the bar of bismuth withdrawn, &c. During this experiment, continued for about *one minute*, the state of the galvanometer was read off at intervals of about 10 seconds.

A second series of experiments was now made, but with this difference, that the commutator assumed that position, on *withdrawing* the bar of bismuth which it had occupied in the first series on *inserting* the bismuth, and *vice versâ*.

(1158) The results were these: The commutator being in the position A, whilst the bismuth was withdrawn, the galvanometer *rose* 2·62; the commutator being in the position B, whilst the bismuth was withdrawn, the galvanometer *fell* 2·10. The extreme end of an *iron* bar being substituted for the bismuth, the induced current was too powerful to be measured; the direction of the needle could alone be observed. The position of the commutator being A, whilst the iron bar was removed, there was a *decrease* in the deflection of the galvanometer; and the position of the commutator being B, there was an *increase* in the deflection of the needle on removing the iron bar, and these results being exactly the reverse of those obtained with the bismuth, prove, (according to Weber,) the induction of electric currents by the diamagnetization of the bismuth, the direction of these currents being constantly the reverse of those induced by iron under the same circumstances, precisely as it should be if the bismuth contained magnetic fluids, or their equivalents (Ampère's currents,) which are set in motion, or rotated under the influence of powerful magnets in exactly an opposite direction to that of iron.

(1159) The apparatus employed by Faraday for the determination of this question is thus described (*Phil. Trans.*, part i., 1850): "A straight wooden lever, 2 feet in length, was fixed by an axis at one end, and by means of a crank and wheel made to vibrate in a horizontal plane, so that its free extremity passed to and fro through about 2 inches. Cylinders of metal, or other substances, 5½ inches long, and ¾ths of an inch in diameter, were fixed in succession to the end of a brass rod, 2 feet long, which itself was attached at the other end to the moving extremity of the lever, so that the cylinders could be moved to and fro in the direction of their length through a space of 2 inches. A large cylinder electro-magnet was also prepared, the iron core of which was 21 inches long and 1·7 inch in diameter; but one end of this core was made smaller for the length of 1 inch, being in that part only 1 inch in diameter. On to this

reduced part was fixed a hollow helix, consisting of 516 feet of fine covered copper wire; it was 3 inches long, 2 inches external diameter, and 1 inch internal diameter; when in its place, 1 inch of the central space was occupied by the reduced end of the electro-magnet core which carried it, and the magnet and helix were both placed concentric with the metal cylinder above mentioned, and at such a distance that the latter in its motion would move within the helix, in the direction of its axis approaching to, and receding from the electro-magnet in rapid or slow succession. The least and greatest distances of the moving cylinder from the magnet during the journey, were $\frac{1}{8}$th of an inch and 2·2 inches. The object, of course, was to observe any influence upon the experimental helix of fine wire which the metal cylinders might exert, either whilst moving to or from the magnet, or at different distances from it.

" The extremities of the experimental helix wire were connected with a very delicate galvanometer, placed 18 or 20 feet from the machine, so as to be unaffected directly by the electro-magnet; but a commutator was interposed between them. This commutator was moved by the wooden lever, and as the electric currents which would arrive at it from the experimental helix, in a complete cycle of motion, or to-and-fro action of the metal cylinder, would consist of two contrary portions, so the office of this commutator was, sometimes to take up these portions in succession, and send them on in one consistent current to the galvanometer, and at other times to oppose them and to neutralize their result; and, therefore, it was made adjustible, so as to change at any period of the time or part of the motion.

" With such an arrangement as this, it is known, that however powerful the magnet, and however delicate the other parts of the apparatus, no effect will be produced at the galvanometer as long as the magnet does not change in force, or in its action upon neighbouring bodies, or its distance from, or relation to, the experimental helix; but the introduction of a piece of iron into the helix, or anything that can influence, or be influenced by the magnet, can, or ought to show a corresponding influence upon the helix and galvanometer. '*The apparatus*,' observes Faraday, 'I should imagine to be almost the same in principle and practice as that of M. Weber, *except that it gives me* CONTRARY RESULTS.' "

To insure steadiness, the machine, the magnet and helix, and the galvanometer stood upon separate tables on a stone floor laid upon the earth, the table carrying the machine being carefully strutted to neighbouring stone work. No iron was employed in any of the moving parts, and great care was taken to prevent the core while in

motion from disturbing in the least degree the experimental helix and magnet. The magnet was excited by a current from 5 pairs Grove's plates, and was then very powerful.

It was observed that on connecting the magnet with the battery, and then the experimental helix with the galvanometer (a very delicate instrument by Ruhmkorff), a current appeared at the latter, which continued a varying time, and which seemed to come from the battery. This current, which it was necessary in these delicate investigations to guard against, was traced to the *time* occupied by the iron core in attaining its maximum magnetic condition. It disappeared after the magnet had been excited a short time, and no experiment was proceeded with till it had entirely ceased.

(1160) On proceeding to experiment with this apparatus, Faraday found that when magnetic metals were used as cores, and such a velocity given to the machine as to cause five or six approaches and withdrawals of the core in one second, the direction in which the needle of the galvanometer moved was consistent with the effect of a magnetic body; but when *diamagnetic* metals were used, the deflection of the needle was in a contrary direction, *but the deflection was not the greatest for the most diamagnetic substances; indeed, the effect with bismuth, antimony, and phosphorus was scarcely appreciable. The effects were proportionate to the conducting power of the substance for Electricity;* and after minutely examining into all the circumstances, and varying the experiments in many ways, Faraday came to the conclusion that they were due to *induced currents* moving through the masses of the diamagnetic substances, and not to any polarity correspondent in its general nature (though opposed in its direction) to that of iron.

(1161) Referring to Reisch's experiments as described by Weber, according to which both N. and S. poles, when they act at the same time on the same side of a piece of bismuth, by no means repel it with the *sum* of the forces which they would individually exert, but only with the *difference* of these forces; Faraday says, that he repeated it "carefully and anxiously, but could never obtain the slightest trace of action with the bismuth." He obtained action with the iron, but in those cases the action was far less than if the iron were applied outside between the horse-shoe magnet and the needle, or to the needle alone, the *magnets being entirely away;* with weak magnetic substances, he did not find the arrangement at all comparable for readiness of indication or delicacy, with the use of a common or an astatic needle.

Faraday also refers to an experiment of Plücker, which at first seems to indicate strongly the polarity of bismuth or phosphorus. If

a bar of either of these substances be suspended horizontally between the poles of the electro-magnet, it will go to the equatorial position with a certain force, passing from stronger to weaker places of action. If a bar of iron of the same size be fixed in the equatorial position, a little below the plane in which the diamagnetic bar is moving, the latter will proceed to the equatorial position with much greater force than before, and this is considered as due to the circumstance that on the side where the iron has N. polarity, the diamagnetic body has S. polarity, and that on the other side the S. polarity of the iron and the N. polarity of the bismuth also coincide.

(1162) It is, however (says Faraday), very evident that the lines of magnetic force have been altered sufficiently in their intensity of direction, by the presence of the iron, to account fully for the increased effect. For, consider the bar as just leaving the axial position and going to the equatorial position,—at the moment of starting its extremities are in places of stronger magnetic force than before, for it cannot be doubted for a moment that the iron bar determines more force from pole to pole of the electro-magnet than if it were away. On the other hand, when it has attained the equatorial position, the extremities are under a much weaker magnetic force than they were subject to in the *same* places before, for the iron bar determines downwards upon itself much of that force which, when it is not there, exists in the plane occupied by the bismuth. Hence, in passing through 90°, the diamagnetic is urged by a much greater difference of intensity of force when the iron is present than when it is away; and hence, probably, the whole additional effect. . . . The effect does not (Faraday thinks) add anything to the experimental proof of diamagnetic polarity, nor can he find any evidence of such a state either in his own experiments or in those by Weber or Reisch, and the actions represented or typified by iron, by copper, and by bismuth remain at present distinct.

(1163) A series of memoirs have recently been published by Von Feilitsch (*Pogg. Ann.*), in which he endeavours to prove that diamagnetic bodies possess a polarity the *same* as that of iron; and in this uncertain state of the subject some admirable experiments were undertaken by Dr. Tyndall, the results of which were laid before the Physical section of the British Association at Liverpool in 1854. That the repulsion of a diamagnetic body depends not alone on the magnet operating upon it, but upon the joint action of the magnet and diamagnet, is proved by the fact that the repulsive force increases not simply in proportion to the strength of the magnet, but to the

square of the strength.* Tyndall confirms the observation of Reisch, that the condition, whatever it may be, which is evoked in a bar of bismuth by one magnetic pole is neutralized by the other; that each pole evokes a condition peculiar to itself, for when a bar of that metal was suspended between the poles of two bar electro-magnets it was repelled when the poles were alike, but remained motionless when the poles were of different names. The most perfect antithesis was observed in all cases between the deportment of a *normal* diamagnetic bismuth bar (a bar in which the planes of principal cleavage are parallel to the length of the bar) and a bar of soft iron; the electric and magnetic forces, which caused a deflection of the former from right to left, produced a deflection of the latter from left to right. The whole of the experiment seemed to justify the presumption, that whatever be the nature of the influences evoked in magnetic bodies by the action of currents or magnets, or of both combined, to an influence of the same nature but antithetical in its manner of distribution, the deportment of diamagnetic bodies is to be referred.

(1164) The following experiment is described by Tyndall as pointing to the conclusion that, whatever the ideal magnetic distribution in iron may be, a precisely opposite distribution occurs in bismuth; or, in other words, that the diamagnetic force is a polar force, but that the polarity is the reverse of magnetic polarity. Two helices were so placed that the end of the soft iron cores which fitted into them, were about 6 inches apart from centre to centre; the helices were at opposite ends of the plane which touched the ends of the cores. A helix of copper wire was introduced, and within it a bismuth bar, 6½ inches long, and four-tenths of an inch in diameter,

* This mark of distinction between those bodies which have their power of exhibiting magnetic phenomena conferred upon them by the magnet, and those whose actions are dependent upon some constant property of the mass, was pointed out by Tyndall and Poggendorff in 1851. It may be illustrated thus: Let M represent the Magnetism of either pole of a magnet, and let M′ be the Magnetism of the opposite pole of a very hard steel bar, then their mutual attraction at a given unit of distance is expressed by the product MM′. If now the power of the pole of the magnet be increased to n M, the mutual attraction will be n MM′, provided, that is, that the steel bar is hard enough to resist magnetization by influence; hence, when a variable magnetic pole acts on an opposite one of constant power, the attraction is proportional to the strength of the former. But, if instead of a hard steel bar, a piece of soft iron (M′) be taken, the Magnetism of which will increase in the same ratio as that of the influencing pole of the magnet, then on increasing the power of the latter from M to nM, the attraction expressed by the product of both will be n^2MM′; that is to say, the attraction of a body magnetized by influence, and whose Magnetism varies as the strength of the influencing magnet is proportional to the *square of the strength* of the latter.

was freely suspended, so that the ends of the bar were opposite to those of the soft iron cores. A current being sent through the helix, if the bismuth bar within it were excited by the current, it was probable that the nature of the excitement would manifest itself in the action of the magnets upon the diamagnetic body. By working delicately, the most perfect mastery was obtained over the suspended bismuth: when the current through the helix flowed in a certain direction, the ends of the diamagnetic bar were repelled by the electro-magnets; when the current flowing through the helix was reversed, the same ends were attracted by the magnet. The same effect was obtained when instead of reversing the helix current, the polarity of the two magnets was reversed. On comparing the deflections with those of soft iron, it was found that they were *perfectly antithetical.* The excitement which caused the ends of the iron bar to be attracted, caused the ends of the bismuth bar to be repelled; while the excitement which caused the ends of the iron bar to be repelled, caused those of the bismuth bar to be attracted.

(1165) If it be true that the polarity of the bismuth bar is the reverse of magnetic polarity, its two ends must, when the current circulates round it, be in different states; but if this is the case, then, if we make the two poles acting upon the ends of the bar *alike*, we ought to have attraction at one end and repulsion at the other; the result of these opposing actions being that the bar must remain undeflected. Tyndall made this experiment, and the result was in accordance with this conclusion. Two magnets with poles of the same name were brought to bear on a bismuth bar, the direction of the force emanating from the two poles being the same, the repulsion of one end and the attraction of the other tended to deflect the bar; two other poles of the same name, but of opposite names to the former two, were then caused to act upon the bar, *i. e.*, four magnets were employed—the two poles to the left being of the same name, and the two to the right of the opposite quality. The bar was promptly deflected, thus corroborating the view that diamagnetic bodies possess a polarity opposed to magnetic bodies.

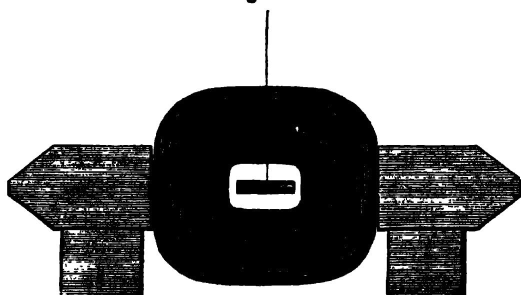
(1166) In the Bakerian Lecture for 1855, Dr Tyndall reinvestigates this interesting subject at great length, and adduces powerful experimental evidence in proof of the *duality* of diamagnetic excitement and of diamagnetic polarity. In experimenting with bismuth, the question of structure must be particularly attended to, for the "setting" of a bar of that metal between the magnetic poles will depend on the relation of the form of the mass to the planes of crystallization. A bar of bismuth whose planes of principal cleavage are throughout parallel to its length, suspended in the magnetic field

with the said planes *vertical*, will set its longest dimension at right angles to the line joining the poles—this is the normal department of diamagnetic bodies, and Tyndall, therefore, calls such a bar, a *normal diamagnetic bar*. On the other hand, a bar of compressed bismuth dust, or a bar of bismuth whose principal planes of crystallization are transverse to its length, will set axial in the magnetic field; such bars he calls *abnormal diamagnetic bars*.

Again, a bar of iron sets with its longest dimension from pole to pole; but a bar of compressed carbonate of iron dust, whose shortest dimension coincides with the line of pressure, sets its length equatorial; the former may, therefore, be called a *normal paramagnetic bar*, and the latter an *abnormal paramagnetic bar*.

(1167) The apparatus employed in examining the separate and joint action of a magnet and a voltaic current on these different bars, is shown in Fig. 456. A helix was formed of covered copper wire, $\frac{1}{20}$th of an inch thick; the space within the helix was rectangular, and was 1 inch long, 0·7 inch high, and 1 inch wide; the external diameter of the helix was 3 inches. Within the rectangular space, the body to be examined was suspended by a fibre which descended through a slit in the helix. The latter was placed between the two flat poles of an electro-magnet, and could thus be caused to act upon the bar within it, either alone or in combination with the magnet. When a *normal*, paramagnetic bar was suspended in this helix, and a current sent through the latter, the bar set its longest horizontal dimension parallel to the axis of the helix, and consequently *perpendicular* to the coils. An *abnormal* paramagnetic bar suspended in a similar manner set its longest dimension perpendicular to the axis of the helix, and consequently *parallel* to the coils. A *normal* diamagnetic bar comported itself in the helix precisely as an *abnormal* paramagnetic bar; and an *abnormal* diamagnetic bar exactly as a *normal* paramagnetic bar.

Fig. 456.



(1168) In examining the conjoint action of the magnet and the helix, eight experiments were made with each particular bar; in the first *four* the *magnet* was excited first, and after the suspended bar had taken up its position of equilibrium, the deflection produced by the passage of a current through the surrounded helix was observed; in

the second four experiments the *helix* was excited first, and when the bar within had taken up its position of equilibrium, the Magnetism was developed and the consequent deflection observed. We give the results of the eight experiments with the *normal paramagnetic bar.* N S (Fig. 457) indicate the N. and S. poles of the electro-magnet; *a b* is the bar of iron; the helix within which the bar was suspended is shown in outline around it; the arrow shows the direction of the current in the *upper half* of the helix.

Fig. 457.

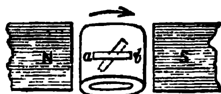


Fig. 458.

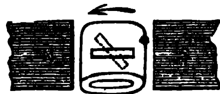


Fig. 459.



Fig. 460.



1°. *Magnet excited first.*—On exciting the magnet, the paramagnetic bar set itself parallel to the line joining the poles, as shown by the unbroken line *a b*. On now sending a current through the helix in the direction of the arrow, the bar was deflected towards the position dotted in the figure; interrupting the current in the helix and permitting the magnet to remain excited, the bar returned to its former position; the current was now sent through the helix in the direction of the arrow (Fig. 458), the consequent deflection was towards the dotted position. In Figs. 459 and 460, all other things remaining the same, the polarity of the magnet was reversed; the deflections of the bar on exciting the helix are shown by the dotted lines.

Fig. 461.

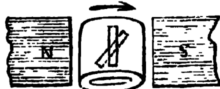


Fig. 462.

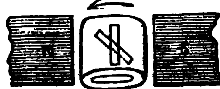


Fig. 463.

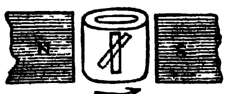
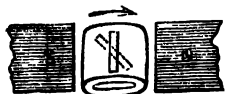


Fig. 464.



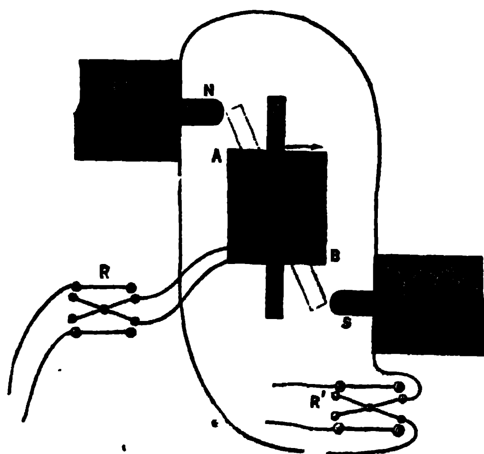
2°. *Helix excited first.*—On passing the current through the helix the bar immediately set its length parallel to the axis of the helix. On now exciting the magnet so that its polarity was that indicated by Fig. 461, the deflection was towards the dotted position. Inter-

rupting the current through both magnet and helix, and reversing the current through the latter, the bar came to rest as before, parallel to the axis. On exciting the magnet as in the last case, the deflection was that shown in Fig. 462. Preserving the same current in the helix, and reversing the polarity of the magnet the deflection was that shown in Fig. 463. Preserving the magnet poles as in the last experiment, and reversing the current in the helix the deflection was that shown in Fig. 464.

(1169) These experiments were repeated under precisely the same conditions with *a normal diamagnetic* bar; the deflections were in each of the eight cases the reverse of those indicated in the figures; they were next repeated with *an abnormal paramagnetic* bar, made of compressed carbonate of iron dust; the deflections were in each case the same with those with the normal diamagnetic bar; and lastly, *an abnormal diamagnetic bar*, consisting of a prism of bismuth, whose principal planes of crystallization were perpendicular to its length, was tested by a mode of experiment the same as that applied in the other cases, and the deflections were found to agree with those of the *normal paramagnetic bar.*

(1170) For examining the question of the "polarity" of diamagnetic bodies, the plan adopted by Tyndall was to cause fixed magnets to act upon a moveable bar of bismuth encircled by an electric current, and to note from the deflections of the bar the character of the force acting upon it. The bar was suspended with great delicacy in the axis of a helix of covered copper wire; opposite to either end of the bar was placed an electro-magnetic spiral, enclosing a core of soft iron. The spirals were so connected together that the same current excited both, so that the same magnetic strength was developed in both poles, and by means of a reverser the polarity of the cores could be changed at pleasure; a current reverser was also attached to the helix enclosing the bismuth bar, so that the current from the battery could be caused to flow through

Fig. 465.



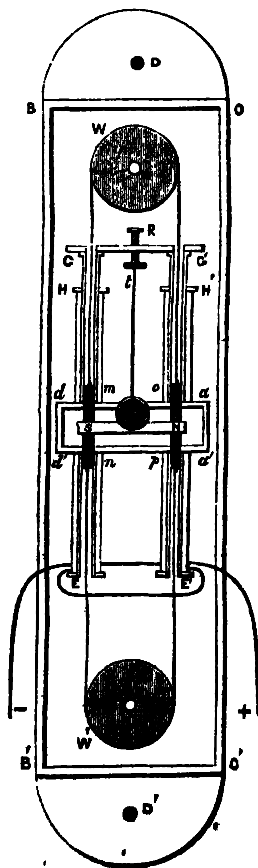
it in either direction. The arrangement will be at once understood by an inspection of Fig. 465. A B, the helix enclosing the bismuth bar; N S, the ends of the cores of the electro-magnets; R′, the current reverser of the spirals; R, the current reverser of the helix. On sending the current through the helix in the direction indicated by the arrow, the magnets being so excited that the pole N. was N. and the pole S., S.; the bar moved from its position, and came to rest in the dotted position, being manifestly *attracted* by the magnets. On reversing the poles of the magnets, the bismuth bar instantly loosed from the position it previously occupied, and receded from the poles; it was now repelled. On now changing the direction of the current through the helix, attraction was again manifested. "In all cases, when the bar was freely moving in any direction under the operation of forces acting upon it, the reversion, either of the current in the helix or the polarity of the cores, arrested the motion; approach was converted into recession, and recession into approach."

(1171) Tyndall has more recently (*Phil. Trans.*, 1856) again investigated this interesting subject with an apparatus based on different principles, and constructed (from a plan furnished by M. Weber,) by M. Leyser, of Leipsic. The diamagnetic bar, suitably excited, is permitted to act upon an astatic system of steel magnets; and from the deflections of the system the polarity of the bar is inferred. The instrument consists essentially of 2 spirals of covered copper wire, about 18 inches long, firmly attached to a massive slab of mahogany. The slab is attached by brass bolts to the solid masonry of the Royal Institution, so as to have the spirals in a vertical position. Above the spirals is a wooden wheel, with a grooved periphery, and below them a similar one. The wheels are united by an endless string, which communicates motion from one of them to the other. To this string the cylinders submitted to examination, are attached; and by turning the lower wheel with a suitable key, the cylinders can be caused to move up and down within the spirals. Two steel bar magnets are arranged astatically, connected by a rigid brass junction, and so suspended that the magnets are in a horizontal plane. The two magnets have the two spirals between them, their poles being opposite the centres of the spirals. When, therefore, a current is sent through the spirals, it exerts no more action upon the magnets than the central or neutral point of a magnet would do. If the bars within the spiral be perfectly central, they also will present these neutral points to the suspended magnets, and hence exert no action upon them. But if the key be so turned that the two ends of the diamagnetic bars shall

act upon the magnets, then, if these bars be polar, the intensity and character of their polarity will be indicated by the deflections of the magnets. Hence, we have not only the action of the earth neutralized, but a turning force is brought to bear upon the suspended system four times that which would come into play if only a single spiral and a single pole were made use of. The instrument is enclosed on all sides from external air currents; the magnets have a mirror attached to them which moves as they move, and which is observed by means of a telescope and scale placed at a distance of about 10 feet from the instrument.

(1172) The apparatus, and the working of its various parts, will be understood by reference to Fig. 466; B O B′ O′ is the outline of the rectangular case, the front of which is removed so as to show the apparatus within. D D′ are the screw holes by which the box is secured firmly to the wall; H E H′ E′ are the copper wire helices wound round 2 brass reels, the upper ends of which protrude from H to G and from H′ to G′; W W′ are the grooved wheels, to the string of which are attached the cylinders, *m*, *n*, *o*, *p*, of the body to be examined; G G′ is a cross-bar of brass, through the centre of which the screw, R, passes, from which the astatic arrangement of magnets, S N, is suspended by silk fibres; the black circle in front of the magnet S N is a mirror, and the rectangle, *d a d′ a′*, is the outline of a copper damper, which, owing to the currents induced in it by the motion of the magnets, soon brings the latter to rest, and thus expedites experiment.

Fig. 466.



(1173) When cylinders of bismuth, copper, antimony, heavy glass, marble, and many other substances were submitted to experiment with this apparatus, very marked deflections were produced. We quote one particular experiment performed by Dr. Tyndall in the presence of Professors Faraday, De la Rive, and Marcet. The bismuth cylinders were 3 inches long and 0·7 of an inch in diameter, and were chemically pure. A current from a single

cell of Grove's battery being caused to circulate in the helices, the cylinders remaining in their centres as in the figure, the cross wire of the telescope cut the number 650 on the scale. Turning the wheel W′ so as to raise the cylinder *m n* and depress the cylinder *o p*, the magnet promptly moved, and after some oscillations took up a new position of equilibrium—the cross wire of the telescope then cutting 670 on the scale. Reversing the motion so as to place the cylinders again central, the former position 650 was assumed; on turning further in the same direction so as to depress *m n* and raise *o p*, the position of equilibrium of the magnet was at the number 630. Hence, by bringing the two ends *n* and *o* to bear upon the astatic magnet, the motion was from smaller to greater numbers, the position of rest being then 20 divisions *greater* than when the bars were central. By bringing the ends *m* and *p* to bear upon the magnet, the motion was from greater to smaller numbers, the position of rest being 20 divisions *less* than when the bars were central.

When the current was caused to flow through the helices in the contrary direction, an opposite result was obtained. The following was the experiment: The bismuth cylinders being in the centres of the helices, the cross wire of the telescope cut the number 482 on the scale. Turning the wheel so as to raise *m n* and depress *o p*, the cross wire cut 468; reversing the motion so as to place the cylinder again central, the former position of 482 was assumed, and on turning further in the same direction so as to depress *m n* and raise *o p*, the number became 493. In this case, therefore, the first motion was from greater to smaller numbers, and the last from smaller to greater.

(1174) In answer to the objection that has been urged against these experiments, that the deflections are due to induced currents aroused in the bismuth by its mechanical motion up and down within the spiral, Tyndall satisfactorily replies—1st, that the deflection produced is *permanent*, which could not be the case if the effect were due to induced currents, which vanish instantaneously. 2ndly, if the effect were due to induction, it would be shown in the most exalted degree by the best conductors. Now, antimony is less diamagnetic than bismuth, but it is a better conductor. The deflection produced by it, however, shows that it is its *diamagnetic* quality, and not its *conductive* quality which is effective; the amount of deflection being less than that of bismuth. Copper is fifty times a better conductor than bismuth, but its diamagnetic capacity is nearly *nil;* it produces no sensible action upon the magnets, which could not possibly be the case were the result due to inductiou.

Both paramagnetic and diamagnetic liquids have been included by

Tyndall in this examination, and the polarity of both has been established.

(1175) *Tyndall's Polymagnet.*—For the exhibition of the various phenomena of Diamagnetism and Electro-magnetism, the apparatus shown in Fig. 467, was devised by Dr. Tyndall. It consists of an

Fig. 467.

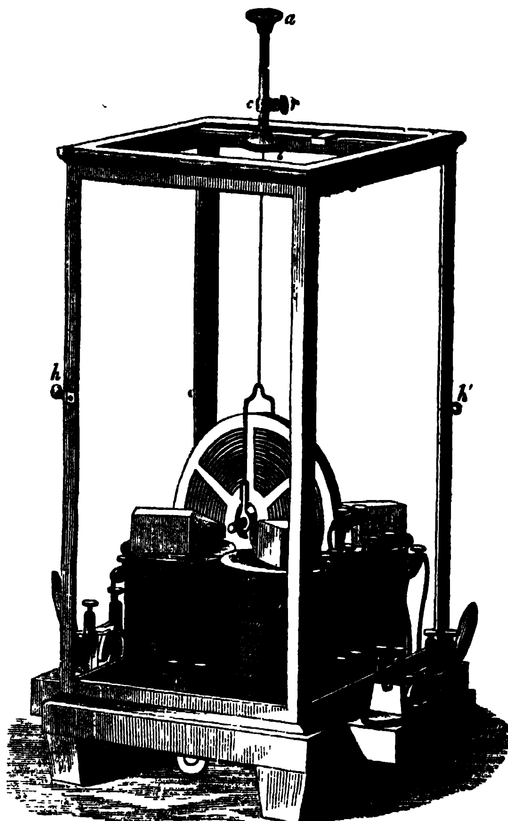
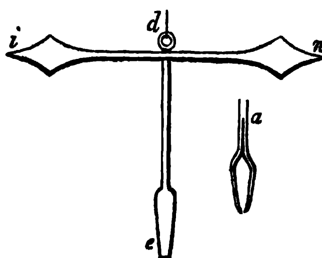


Fig. 468.



arrangement of two horseshoe magnets, a helix of covered copper wire disposed between them, and a suitable means of suspension. The diameter of the soft iron cores is 1·125 inch, and their distance apart from centre to centre 4·85 inches. The diameter of the covered copper wire surrounding the cores is 0·1 inch, and the weight of it which surrounds each limb of the magnet is 12 pounds. The helix placed between the two electro-magnets has an internal diameter of 1 inch, an external diameter of 8 inches, and measures along its axis 1·15 inch. The diameter of its wire is 0·065 of an inch, and its weight is 6 pounds. It is wound so as to form a double coil, and is held compactly together by radial strips of brass. A simple current reverser is fixed on the base-board of the instrument, which, to preserve a still atmosphere, is surrounded by a glass case. In the figure a bismuth bar is represented as suspended within the helix by several fibres of unspun silk attached to the central rod which passes through the top of the glass case. The bar is 6 inches long and ·4 of an inch in diameter. When suspended so as to swing freely within the helix, its ends lie between the movable masses of iron which rest upon the electro-magnetic cores. Four poles are thus brought simultaneously to bear upon the bar of bismuth, and its action is thereby rendered both prompt and energetic. The two poles to the right of the bar must both be of the same name, and the two to the left of the bar of the opposite quality. If those to the right be both N., those to the left must be both S., and *vice versa*. On sending a current from 10 or 15 cells round the helix, and exciting the magnets by a battery of 4 or 5 cells, the current reversers place the deflections of the bar entirely under the control of the experimenter. By changing the direction of the current in the helix by means of its reverser, a change of deflection is produced. The same is effected if the polarity of the magnets be changed by the reverser which belongs to them.

All the experiments that are usually made with an upright electro-magnet may be made with this instrument, the various parts of which may with great facility be lifted separately out of the case; and numerous experiments will suggest themselves to those acquainted with what has been done of late years in Diamagnetism.*

(1176) *Diamagnetic Conditions of Flames and Gases.*—At the meeting of the Physical section of the Ninth Italian Scientific Congress in Venice, 21st of September, 1847, a memoir on the Universality of Magnetism was read by Padre Bancalari, Professor of Physics in the

* The instrument above described was constructed by Mr. Becker, of Newman Street, and the same ingenious mechanician has recently completed a very perfect and elegant apparatus of a similar nature for Mr. J. Strange.

Royal University of Genoa; and on the 27th of the same month it was announced by the reporter that it had been proved in the presence of several philosophers, "that on the interposition of a flame between the poles of an electro-magnet, it was repulsed at the instant the electric current was closed, to return to the first position the instant it was broken." This experiment was repeated shortly afterwards by Professor Zantedeschi, not at first with satisfactory results, but he afterwards fully confirmed Bancalari's experiments, "having," as he says, "constantly observed repulsion in the act of closing the circle, which lasted the whole time that the Magnetism was kept up, and when in the act of opening the circle, he saw the flame return to its primitive position."

(1177) A further study of the phenomena gave Zantedeschi the following results: He found that the phenomenon occurs with contacts of both solid and hollow soft iron, showing that the movement of the flame was not attributable to currents of air.

2nd. That the repulsion when it is quite distinct, and the flame quite pure and terminated in a well-shaped top, is accompanied by a depression.

3rd. That, *cæteris paribus*, the greatest effect takes place when the flame is touching the convex of the magnetic curves indicated by iron filings.

4th. That the action is null, or almost null, when the flame is placed in the centre of the interval which separates the two contacts.

5th. That in the manifestation of the effects it is not necessary for the contacts to be *entirely* separated.

6th. That there is a certain mass of the keeper pieces which is the most efficacious; beyond a limit, which can be shown by experiment, *increase* of the mass causes a *diminution* in the effect.

7th. That the movements of the flame increase with the number of the battery plates.

(1178) Faraday repeated Bancalari's experiment with the large electro-magnet belonging to the Royal Institution. The two terminal pieces of iron forming the *vertical* magnetic poles, were each 1·7 inch square and 6 inches long, but the ends were shaped to a form approaching that of a cone, of which the sides have an angle of about 100°, and the axis of which is horizontal, and in the upper surface of the pieces of iron. The apex of each end was rounded—nearly *a tenth* of an inch of the cone being in this way removed. When these terminations are brought near to each other, they give a powerful effect in the magnetic field, and the axial line of magnetic force is of course horizontal, and on a level nearly with the upper surface of the bars.

(1179) His results were as follows:—

When the flame of a wax taper was held near the axial line but on one side or the other; about one-third of the flame rising above the level of the upper surface of the poles, as soon as the magnetic

Fig. 468.

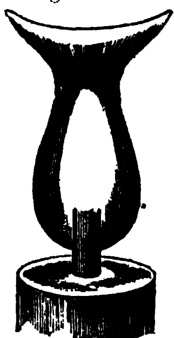
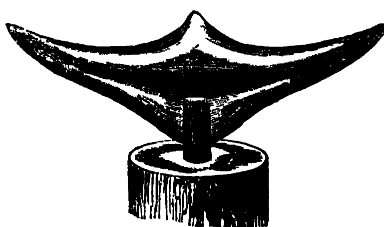


Fig. 469.



Fig. 470.



force was on, the flame was affected, and receded from the axial line, moving equatorially, until it took an inclined position, as if a gentle wind was causing its deflection from the upright position—an effect which ceased the instant the Magnetism was removed. The effect was not instantaneous, but rose gradually to a maximum. It ceased very quickly when the Magnetism was removed. The progressive increase is due to the gradual production of currents in the air about the magnetic field, which tend to be, and *are* formed on the assumption of the magnetic conditions in the presence of the flame.

When the flame was placed so as to rise truly across the magnetic axis, the effect of the Magnetism was to *compress* the flame between the points of the poles, making it recede in the direction of the axial line from the poles towards the middle transverse plane, and also to shorten the top of the flame (Fig. 468).

On raising the flame a little more, the effect of the magnetic force was to increase the intensity of the results just described, and the flame actually became of a *fish-tail shape* disposed across the magnetic axis (Fig. 469.)

(1180) If the flame was raised until about two-thirds of it were

above the level of the axial line, and the poles approached so near to each other (about 0·3 of an inch) that they began to cool and compress the part of the flame at the axial line, yet without interfering with its rising freely between them, then on rendering the magnet active the flame became more and more compressed and shortened, and as the effects proceeded to a maximum the top at last descended and the flame no more rose between the magnetic poles, but spread out right and left on each side of the axial line *producing a double flame with two long tongues* (Fig. 470).

When the magnet was thrown out of action, the flame resumed its ordinary upright form between the poles at once, being depressed and redivided again by the renewal of the magnetic action.

When a small flame only about ⅓rd of an inch high was placed between the poles, the magnetic force instantly *flattened it* into an *equatorial disc.*

(1181) Remarkable results are obtained with the dense stream of smoke rising from a blown-out green wax taper.

When the ignited wick is held about an inch below the axial line, the smoke rises vertically in one column until about ⅔rds of that distance is passed over, and then it divides, going right and left, leaving the space between the poles clear. As the taper is slowly raised, the division of the smoke descends, taking place lower down until it occurs upon the wick at the distance of 0·4 or 0·5 of an inch below the axial line. If the taper be raised still more, the magnetic effect is so great as not only to divide the stream but to make it *descend on each side* of the ignited wick, producing a form resembling that of the letter W; and at the same time the top of the burning wick is greatly brightened by the stream of air that is impelled downwards upon it. In these experiments the magnetic poles were only ·25 of an inch apart. Faraday has even succeeded in affecting the smoke from a small spark by a *good ordinary magnet.*

(1182) In searching into the cause of these phenomena Faraday began by examining the effect of *heat alone* in conducing to the diamagnetic condition of flame. For the burning taper he substituted a helix of fine platina wire, which could be placed in any position and ignited by a voltaic battery. When the helix was placed directly under the axial line, the hot air rose up between the poles freely, being rendered evident above by a thermometer, or by burning the finger, or even by scorching paper; but as soon as the magnet was rendered active, *the hot air divided into a double stream and was found ascending on the two sides of the axial line;* but a *descending* current was formed between the poles, flowing downwards

towards the helix and the hot air, which rose and passed off sideways from it.

(1183) This experiment showed that *hot* air is *more diamagnetic* than *cold* air, and by the following beautiful experiment Faraday proved that air artificially cooled is with relation to air at the natural temperature actually *magnetic*. A stream of air was conducted through a tube surrounded by a freezing mixture, and then directed downwards a little on one side of the axial line into a tube containing a delicate air thermometer, which of course immediately fell; on rendering the magnet active, *the thermometer rose*, but on bringing the tube *under* the axial line it again fell, showing that the cold current of air had been drawn inwards or attracted towards the axial line; i.e., had been rendered magnetic in relation to air at the ordinary temperature.

(1184) This extraordinary effect of heat in increasing the diamagnetic condition of bodies seems to be confined to gases and vapours, Faraday could not detect any distinct increase of the force by heating cylinders of copper and silver to redness.

(1185) Common air being thus shown to have a decided magnetic relation, Faraday proceeded to examine other gases and vapours for which he employed the following ingenious apparatus:—

A Woulf's bottle was provided, having three apertures *a*, *b*, *c*; into *a*, a wide tube was fixed descending within the bottle to the bottom, being open above and below; by this water could be poured into the bottle, and employed to displace the gas previously within it. Aperture *b* was closed with a stopper; aperture *c* had an external tube with a stop-cock fixed in it to conduct the gas to any place desired. To expel the gas and send it forward, a cistern of water was placed above the bottle, and its cock so plugged by a splinter of wood, that when fully open, it delivered only 12 cubic inches of fluid in a minute. This stream of water being directed into aperture *d*, and the cock of tube *c* open, 12 cubic inches of any gas within the Woulf's bottle were delivered in a minute of time, and this proportion was found not sufficiently great to *deluge* the magnetic field.

In order to deliver the gas at the magnetic poles, a piece of tube bent at one end nearly to a right angle was held by a clamp in a moveable position, so that its vertical part could be placed anywhere below the axial line; the aperture of this tube was about $\frac{1}{8}$th of an inch in diameter. In the horizontal part, near the angle, was placed a piece of bibulous paper, moistened when necessary with strong solution of muriatic acid. If the gas to be employed as a stream was heavier than the surrounding medium, then the glass tube was so bent as to deliver its stream downwards, and over the axial line.

(1186) The next point was to detect and trace the course of these streams. This was effected by arranging upon little stands a set of tubes of thin glass, open at both ends, and about the size and length of a finger. These tubes could be readily adjusted at pleasure, either over or under the magnetic poles. When they were over the poles, three tubes were generally used, one *over* the axial line, and one at each side. When they were under the poles the low end was turned up a little for the purpose of facilitating observation.

Now, the gas issuing from the delivering tube had diffused through it a little invisible muriatic acid vapour, and to make it evident into which of the "catch" tubes it passed, a piece of bibulous paper moistened with ammonia was suspended in each, and it was evident at once by the *visible fume* formed at the top of one of the tubes, whether the gas delivered below passed up the one or the other tube, and which; and yet the gas was perfectly clear and transparent as it passed to the place of magnetic action. To preserve the air in a tranquil state, a little sheltering apparatus of mica was built up round the poles.

(1187) To try the working of the apparatus, *air* was sent in; the stream being directed by the axial line, the fume appeared in the *catch* tube above, whether the magnet was active or not, just as it should have done.

Nitrogen—When sent from below upwards, it passed by the axial line into the catch tube above; but when the magnet was made active *a fume appeared in the side tubes as well.* The jet was now arranged a little on one side of the axial line, so that without the magnetic action it still went into the middle tube; on making the magnet active a great portion of it was sent to the side catch tube, thus showing that in relation to atmospheric air nitrogen *is* at the same temperature *diamagnetic.*

Oxygen—When sent from above downwards through air between the poles, it descended vertically, whether the magnet was excited or not; when it was made to descend on one side of the axial line it was deflected and drawn *towards* the axial line, thus showing either that in common air oxygen *is magnetic*, or that it is less *diamagnetic* than a mixture of oxygen and nitrogen.

Hydrogen—In spite of its lightness it was deflected, and sent equatorially, proving it to be strongly diamagnetic.

Carbonic Acid—In air it was *diamagnetic;* its course was traced by a glass containing lime water placed beneath the lower end of the catch tube. The stream was sent downwards, a little on one side of the axial line, the tube and lime water being placed further out, so

that the gas should fall clear of it when the magnetic power was not on. On rendering the magnet active, the lime water became turbid. This made a beautiful experiment.

Carbonic oxide—*More* diamagnetic than carbonic acid.

Nitrous oxide—Moderately diamagnetic.

Nitric oxide—Very slightly diamagnetic.

Olefiant gas, coal gas, sulphurous acid gas, muriatic acid gas, hydriodic acid gas, fluosilicon, ammonia, chlorine, iodine, bromine, and *cyanogen,* were all more or less diamagnetic in air.

Of all the vapours and gases tried, *oxygen* seems to be that which has the least diamagnetic force, and this is the cause of the comparatively low diamagnetic condition of atmospheric air.

(1188) Faraday then surrounded the poles of the magnet with a mica chamber, which could be filled with carbonic acid gas; the former arrangements in respect to the magnetic field, the delivery tube, catch tubes, &c., being preserved, he found *air* and *oxygen* passed to the magnetic axis, being, therefore, *less* diamagnetic than carbonic acid gas. On the other hand:—

Nitrogen, hydrogen, coal gas, olefiant gas, muriatic acid gas, ammonia, and *nitrous oxide* passed equatorially, and were all, in a greater or less degree, diamagnetic in relation to carbonic acid.

(1189) By covering the poles of the magnet with a French glass shade, similar experiments were made with *hydrogen* and *coal gas* with the following results:—

In *coal gas*—*Air* passed feebly to the axial line; *oxygen* had the appearance of being *strongly magnetic,* presenting a striking phenomenon, and *nitrogen* was clearly *diamagnetic.*

In Hydrogen—*Air* passed feebly to the axial line, *nitrogen* was strikingly *diamagnetic,* and *oxygen* as strikingly *magnetic. Nitrous oxide, ammonia, carbonic acid, carbonic oxide,* and *olefiant gas* were *diamagnetic.*

The most striking circumstances in these experiments are the strongly marked diamagnetic character of *nitrogen,* and the feeble diamagnetic condition of oxygen, standing as it does, in this respect, far apart from all other gaseous substances.

(1190) Faraday then examined the influence of heat:—

Hot oxygen was powerfully *diamagnetic* in an atmosphere of *cold* oxygen.

Hot carbonic acid was diamagnetic to *cold* carbonic acid. The relation of hot and cold hydrogen could not be ascertained, as Faraday could not succeed in heating the platinum helix which he employed in these experiments by the voltaic battery in an atmosphere of hydrogen, in consequence, as he supposes, of the rapidity with which

that gas is heated and cooled in comparison with other gases. In short, however, all the experiments went to prove that all gases are more diamagnetic when *hot* than when *cold.*

(1191) *Non-Expansion of Gaseous Bodies by Magnetic Force.*— Taking common air as a standard, it appears from the preceding experiments that *nitrogen* and many other gases are strongly *diamagnetic* in relation to it, whilst oxygen has the appearance of a magnetic body. It appears also that the diamagnetic character of flame is due chiefly to the heated state of the gaseous portions.

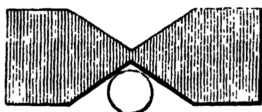
It occurred to Faraday that if the particles of a diamagnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, such a gas should tend to become enlarged or expanded in the magnetic field. On the other hand, if a gas were magnetic, then the force cast upon the particles by the direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere, would tend to cause *contraction* or *diminution of bulk.*

(1192) A change in the bulk of air in the magnetic field had been observed by Plücker; Faraday was, therefore, induced to submit the matter to a minute examination; the result of which was that in none of the gases tried, whether considered as magnetic or diamagnetic bodies, could any alteration in volume be effected by the magnetic force, whether in fields of equal power, or in places where the power is rapidly diminishing; and this result he considers very important in relation to the true nature of magnetic force, either as existing in, or acting upon the particles of bodies. Faraday made similar experiments with liquids, but with very delicate apparatus and powerful electro-magnets, he was unable to observe any change of volume, neither could the least change be observed in the volume of iron or bismuth, however powerful the magnetic force to which they were submitted, and he could obtain no evidence that the magnet exerts any direct power of attraction or repulsion on the particles of gases, or that they move in the magnetic field as they are known to do by any such immediate attraction or repulsion.

(1193) *Differential Magnetic Action of Gases.*—The cause of the diamagnetic change of place is believed by Faraday to be a differential result depending on the *differences* of the two portions or masses of matter occupying the magnetic field; and in the case of gases, the phenomena may be produced and examined in a very useful manner by the employment of soap bubbles. In Faraday's experiments, these bubbles were about ½ an inch in diameter, and by employing

recently-prepared *cold soap water*, and a bent glass tube connected with a bladder and stop-cock, he was able with a little care to blow them of a nearly uniform size and thickness. The gases were examined by placing the bubbles in the angle of a double pole of iron arranged between the poles of the large electro-magnet. When the bubble was of *air*, and a power of 20 pairs of plates employed, it was deflected slightly outwards from the axial line, the deflection being due to the water of the bubble. This deflection served as a correction in experiments with other gases.

Fig. 471.



Nitrogen was driven equatorially with great force, forming a striking experiment when it is considered that this gas constitutes ⅘ths of the atmosphere.

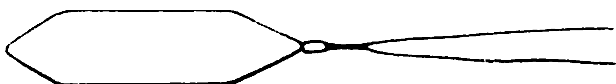
Oxygen was pulled inwards *towards the axial line* with much force, exactly as if it were highly magnetic.

Nitrous oxide and olefiant gas were both driven equatorially.

The other experiments with gases were quite in accordance with those already described, and all tended to prove that the effect is a differential result of the masses of matter present in the magnetic field.

(1194) *Magnetic Characters of Oxygen, Nitrogen, and Space.*—In order to examine the differential action of two gases, tubes the size and shape of fig. 472, of thin flint glass, were filled with the gases and having been sealed up hermetically, they were fastened by means

Fig. 472.



of sealing wax to loops of thread, by which they were suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis. Now, when so suspended, if the gases are both alike in magnetic or diamagnetic power, their position will not be altered on the supervention of the magnetic force; but if one gas is more diamagnetic than another, the *most* diamagnetic will move outwards equatorially, pulling the *least* diamagnetic inwards, till the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium. Their relative diamagnetic intensities can then be measured by the force required to restore them to their equidistant position from the magnetic axis.

(1195) The tubes being filled respectively with oxygen and nitro-

gen, a most striking effect was observed the moment the magnetic force was thrown into action. The oxygen tube was carried inwards towards the axis, and the nitrogen tube driven outwards on the contrary side. When the tubes had taken up their new position, the oxygen tube was about $\frac{1}{8}$th of an inch from the iron of the core, and the nitrogen tube $\frac{3}{8}$ths distant, and *ten* revolutions of the torsion axis altered only in a slight degree these relative distances.

(1196) The effect of rarefaction was then tried; bulbs the size and shape of Fig. 473, were filled with oxygen, and then reduced under

Fig. 473.



the air pump, so that one tube contained gas at the pressure of one atmosphere; a second, gas at half an atmosphere, or 15 inches of mercury; a third, gas at the pressure of 10 inches of mercury; and a fourth, after being filled with oxygen, was reduced to as good a vacuum as an excellent air-pump could effect.

On trying these tubes one against the other, the expanded portion was always driven away, the denser gas going inwards; and when the tube containing gas at one atmosphere pressure was opposed to the vacuum, the former passed axially with such power that it was evidently only the diamagnetic power of the glass tube that prevented it from passing against the iron core, and occupying the centre of the magnetic field.

Oxygen, then, is a very magnetic substance, its magnetic force being in proportion to its density.

With *nitrogen* the differences produced by rarefaction could not be detected, there being no perceptible difference between the tube of gas at one atmosphere pressure, and that reduced as nearly as possible to a vacuum; both tubes remained equidistant from the magnetic axis.

Nitrogen, then, is neither magnetic nor diamagnetic: it is equivalent to a vacuum. Magnetically considered, *it is like space itself*, which may be considered *zero*.

(1197) The lines of magnetic force can traverse *pure space* just as gravitating force does, and as static electric forces do; space, therefore, has a magnetic relation of its own, which will probably, hereafter, be found to be of the utmost importance in natural phenomena. The true zero is represented by such bodies as when added to space produce no magnetic or diamagnetic effect. The term *magnetic*, Faraday

proposes, should be a general one, and include *all* the phenomena and effects produced by the power, and he proposes that bodies magnetic in the sense of iron should be called *paramagnetic* bodies (as placing themselves parallel to the lines of magnetic force), so that the division would stand thus—

Magnetic . . . { Paramagnetic.
{ Diamagnetic.

(1198) Amongst all the gases hitherto examined, there is nothing that compares with oxygen; its magnetic power is so great that it makes atmospheric air a magnetic medium of no small power, which must be taken into consideration when experimenting on the diamagnetic condition of other gases. The discovery of the high magnetic condition of oxygen and its variations with variations of temperature and density, suggests an explanation of the cause of the variations of the magnetic force which are now so carefully watched on different parts of the surface of the globe, of the daily and annual variation of the needle, and of the relation between the aurora borealis and the Magnetism of the earth.

(1199) *Magnetic Conducting Power—Atmospheric Magnetism—Magnetic Conduction.*—The remarkable results respecting oxygen and nitrogen just described, led Faraday to the idea that if bodies possess different degrees of conducting power for Magnetism, that difference may account for all the phenomena, and its further consideration may assist in developing the nature of magnetic force. By the term *conducting power*, he means to convey a general expression of the capability which bodies may possess of effecting the transmission of magnetic force, and not to imply anything as to how the process of conduction is carried on; so that if a medium of a certain degree of conducting power occupy the magnetic field, that body will be displaced if another substance possessed of better conducting power be introduced into the field—the result being a *differential effect* of their difference in conducting power.

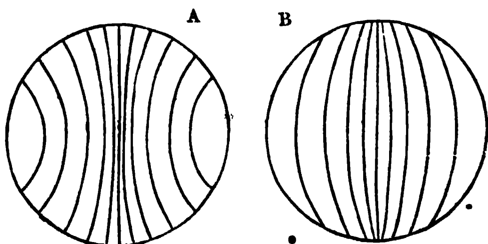


Fig. 474.

(1200) In pure space the lines of magnetic force are straight and parallel; if a *paramagnetic* body be introduced, the lines are no longer straight, but there will be a concentration of them on the conducting body, so that the space occupied by the conducting body trans-

mits more magnetic force than before (Fig. 471 A). If a *diamagnetic* body be introduced, there will be a divergence of the lines, and the space occupied by the diamagnetic body will transmit less force than before. (Fig. 471 B).

The two bodies affect, *first*, the direction of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space; *secondly*, the *amount* of force in any particular part of the space within or near them, and the influence of this disturbance is easily made manifest experimentally. A small sphere of iron, exactly equidistant from the iron poles, is in a position of unstable equilibrium, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces. If the iron be a spheroid, its greatest diameter points axially, and the circumstances are more favourable for the concentration of force in the axial line passing through the iron than before. The converse is the case with diamagnetic bodies, which find their place of stable equilibrium in the spot where the position of paramagnetic bodies is unstable. Their relative and reverse positions in a field of equal magnetic force, may be retained in the mind by conceiving that if a liquid sphere of a *paramagnetic conductor* were in the place of action, and then the magnetic force developed, it would change in form and be prolonged axially, becoming an *oblong spheroid*, whereas, if such a sphere of diamagnetic matter were placed there, it would be extended in an equatorial direction, and become an *oblate spheroid.*

(1201) The mutual action of two portions of paramagnetic matter in a field of equal magnetic force is that of repulsion, and it is precisely the same with two portions of diamagnetic matter. Faraday found that when the lines of power passing across the magnetic field were strengthened by placing in the field a saturated solution of protosulphate of iron, a small moveable cylinder of phosphorus suspended in the middle of the magnetic field was distinctly repelled by another piece held close to it. Also, when a piece of phosphorus was suspended in water in a field of equal magnetic force, it was repelled equatorially by another piece of phosphorus, but attracted by a tube filled with a saturated solution of protosulphate of iron.

Thus, then, *paramagnetic* and *diamagnetic* bodies attract each other equatorially in a mean medium, but each repels bodies of its own kind.

(1202) *Conduction Polarity.—Paramagnetic* polarity consists in the *convergence* of the lines of magnetic force on to two opposed parts of the body, which are to each other in the direction of the magnetic axis. The difference of character of the new poles is at

these parts very great. Faraday thinks it not improbable that polar attraction or repulsion may exist in oxygen, and in all paramagnetic bodies consistent with the attraction and repulsion of magnets having correspondent poles.

Diamagnetic Conduction Polarity is a different matter. It consists in a *divergence* of the lines of power on *to*, or a convergence *from*, the parts which being opposite are in the direction of the magnetic axis. This polarity is to be carefully distinguished from that which depends upon the reversion of the direction of the power; the latter Faraday considers as a property of the particles of magnetic matter, the former as dependent rather upon the action of the mass; the latter is an absolute inversion of the direction of the power, the former only a divergence or deflection of it.

(1203) Though Faraday speaks of iron as illustrating the action of paramagnetic conductors, he draws an important distinction between the polarity of a magnet and the polarity due to mere conduction. A permanent magnet has a polarity in itself which is possessed also by its particles, and this polarity is essentially dependent upon the power which the magnet inherently possesses. The polarity of a conductor is simply a consequence of the condensation or expansion of the lines of force, and is not due to a determinate arrangement of the cause and source of magnetic action. Speaking figuratively, the difference may be compared to that of a voltaic battery, and the conducting wires or substances which connect its extremities. The stream of force passes through both, but it is the battery which originates it, and also determines its direction; the wire is only a better or worse conductor, however, by variation of form or quality, it may diffuse, condense, or vary the stream of power.

(1204) Applying the idea of conduction to magne-crystallic bodies, Faraday thinks that the special results may be understood by supposing that a magne-crystallic body *conducts* better in the *direction* of the magne-crystallic axis than in any other direction, and he concluded, that if a symmetrical crystal of bismuth were carefully examined in different directions, it would be found to be *less* diamagnetic when its magne-crystallic axis is parallel to the axis of magnetic force than when it is perpendicular to it. By means of the differential torsion balance, he was able to make the trial, and found the results as he anticipated. With calcareous spar he was not able, with his present balance, to establish any difference; but concludes that it will prove most diamagnetic when its optic axis, being in a horizontal plane, is placed parallel to the magnetic axis.

(1205) The place and position of iron in a field of equal force, is the result of the extraordinary power which it has of transmitting

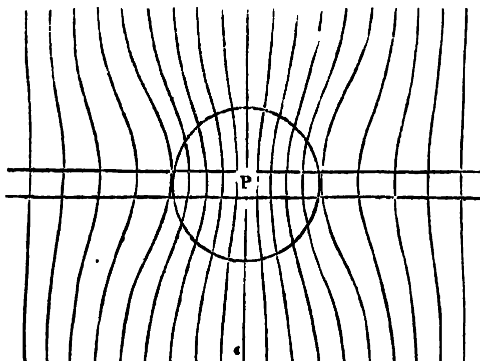
the magnetic force across the space which it occupies, and Faraday accepts the converse phenomena as to the place and position of a diamagnetic body as a proof that it has less power of transmitting the magnetic force than the space it occupies.

(1206) *Atmospheric Magnetism.*—The earth may be assumed to be a mighty compound magnet, the lines of force issuing from the northern and southern parts with different corresponding degrees of inclination, and inclining to, and coalescing with each other over the equatorial parts. The atmosphere consists of 4 volumes of nitrogen and 1 volume of oxygen, or by weight of 3½ parts of the former and 1 part of the latter. These substances are nearly uniformly mixed throughout, so that as regards their manner of investing the earth, they act magnetically as a single medium; nor does there seem to be any tendency in the terrestrial magnetic forces to cause their separation, though they differ very strikingly in their constitution as regards this power.

As regards the magnetic force *nitrogen* is a very indifferent body, being neither diamagnetic nor paramagnetic, whether in a dense state or in a rare state, or whether hot or cold. As regards the magnetic force *oxygen* is highly *paramagnetic*, increasing in force as its temperature is lowered, and diminishing as its temperature is raised, and these properties it carries into the atmosphere, which becomes therefore a highly magnetic medium, varying however in intensity by alterations in its temperature and density.

(1207) Faraday assumes as a *type case* the existence of two globes of air distinct from the surrounding atmosphere by a difference of temperature or a difference of density; that one of these globes is colder or denser than the contiguous parts, and that it is in a portion of space which, without it, would present a field of equal magnetic force. The air of such a globe will facilitate the transmission of the magnetic force through the space which it occupies, determining more lines of force through it than elsewhere. The disposition of these lines, in respect to the line of the dip of the place will be something like what is represented in Fig. 475, and

Fig. 475.



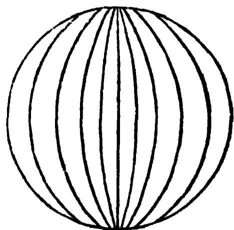
consequently the globe will be polarized as a conductor of the para-magnetic class. Hence the intensity of the magnetic force and its direction will vary not only *within* but *without* the globe, and these will vary in opposite directions, in different places, under the influence of laws which are perfectly regular and well known.

(1208) Now a magnet used as an intensity test will indicate a less intensity at P, because the conducting power of the globe has been increased in consequence of its coldness and density. If on the other hand the globe were warmer or more rarefied than the surrounding space, it would convey less power as being a worse conductor, and the magnet would set with greater force, and give an indication of greater intensity both *within*, and equatorially *without* the globe.

But if changes in the medium can effect the magnet, a magnet ought to make a greater number of vibrations in an atmosphere of nitrogen than in one of oxygen, because these two gases differ naturally in their magnetic relations.

(1209) If another typical globe of air be assumed having a higher temperature than the surrounding air, its condition will be that of a diamagnetic conductor, and it will have power to affect both the intensity and direction of the lines of force in conformity with the action of the former globe, but in the contrary order, although the conditions of the foregoing *typical* globes can never actually occur in nature, still the comparison holds in principle, and we may expect that as the sun leaves us on the *west* some effect correspondent to that of the approach of a body of cold air from the *east* will be produced, which will increase and then diminish, and be followed by another series of effects as the sun rises again and brings warm air with him.

Fig. 476.



(1210) Again, there is more air by weight over a given portion of the surface of the earth at latitudes from 24° to 34°, than there is either at higher latitudes or at the equator, and that should cause a difference from the disposition of the lines of force which would exist if there were equality in that respect. The temperature also of the air is greater at the equatorial parts than in latitudes N. and S. of it; and as an elevation of temperature diminishes the conducting power for Magnetism, so the proportion of force passing through these parts ought to be *less*, and that passing through the colder parts *greater*, than if the temperature of the air were at the same mean degree over the whole surface of the globe.

(1211) *Annual and Daily Variation.*—The effect of the approach and retreat of the sun in his daily course is to produce such variations of changes in the temperature and expansion of the atmosphere, as to influence the lines of force emanating from the earth both in their direction and intensity; the manner in which this influence may be developed, Faraday, by means of figures and descriptions, states, in relation to the annual and daily variation, and the irregular perturbations of the magnetic force, which he thinks are consequences of it. He then applies the result of the magnetic observations at Hobarton* as a test of the probable truth of the hypothesis, and considers that it affords strong confirmation. The upper or N. end of the needle there goes W. till about 21 o'clock, whilst the dip increases; the dip still increasing till noon, the upper end returns rapidly E. as the sun passes by until 2 o'clock the dip then decreasing, after which the needle goes W. again following the sun. On examining the results at Toronto, corresponding effects were found to occur, when the upper or S. end of the needle was considered, and therefore in accordance with the hypothesis.

Faraday also discusses the observations made at Greenwich, Washington, Lake Athabusca, Fort Simpson, and St. Petersburg, and considers them as adding further confirmation. By the aid of these observations he re-states his principles more minutely, endeavouring to indicate what difference changes in the inclination, declination, place of sun, land, sea, &c. will produce.

(1212) Though the sun is the cause of those changes in the atmosphere which affect the lines of force on the earth, he is not assumed as the centre of action as regards those lines; *that*, is considered to exist somewhere in the atmosphere. It appears to be in the upper regions and not on the surface of the earth, because it increases the dip of places N. and S. of the tropics, which have a certain amount of inclination, as at Hobarton and Toronto, both in summer and winter, but it diminishes the dip at places which are within the tropics, and with little inclination, as at St. Helena. By other kinds of observations it appears to be in advance of the sun. All the phenomena indicate that the sun does not act *directly* on the needles at different places, but mediately through its effect on the atmosphere.

(1213) The probable cause of numerous irregular variations, such as those that are shown in the photographic processes of record at Greenwich and Toronto, are then considered, and Faraday thinks that changes in the lines of magnetic force may be produced by the

* "Magnetical and Meteorological Observations. Hobarton, vol. i. 1850." Sabine, Toronto.

varying pressure of the atmosphere, by the occurrence of winds and large currents of air, of rain, and snow; by the passage of those masses of warm and cold air which the meteorologist recognizes in the atmosphere, by the aurora borealis, &c. He thinks it very possible that masses of air at different temperatures may be moved by the magnetic force of the earth, according to the principles of differential action made manifest in the experiments on warm and cold oxygen, in which case, material as well as potential "*magnetic storms*" may exist.

(1214) Faraday, at the conclusion of this paper (26th Series), again alludes to the wonderful magnetic power of *oxygen*. It is in the *air* what *iron* is in the *earth*, and its striking contrast with the nitrogen which dilutes it in the atmosphere, impresses the mind, and by the difference, recalls that which also exists between them in relation to static Electricity and the lightning flash. He expresses his conviction, that there is much to do with oxygen relative to atmospheric Magnetism; and he starts the question—What is the final purpose in nature of its magnetic condition in the atmosphere, liable as it is to annual and diurnal variations, and to entire loss by entering into combination? That it has an important purpose to serve is evident, for nothing in nature is superfluous.

CHAPTER XXII.

MAGNETIC HYPOTHESES.

Notions of the Ancients—Theories of Descartes and Œpinus—Ampère's electro-dynamic theory—Faraday's researches—Lines of magnetic force—The moving wire as an examiner of magnetic forces—Magnetic "polarity"—Physical character of the lines of magnetic force—Places of no magnetic action—Faraday's view of the condition of a magnet.

(1215) The notions entertained by the ancients respecting the immediate source of the power of the magnet, were of the wildest description. Thus Thales and Anaxagoras conceived that the magnet was possessed of an immaterial spirit, in obedience to which iron moved and was attracted; Cornelius Gemma said, that invisible rays pass between the iron and the magnet; others, that there exists a sympathy between them; Epicurus supposed that the atoms of the iron were hooked on to those of the magnet; Plutarch thought that there was an emanation proceeding from the magnet. Cardan said, that iron is attracted because it is *cold*, and Costeo de Lodi regarded iron as the natural food of the magnet. Then came Descartes, whose theory of vortices was for a long time universally adopted. According to his theory, a rush of subtle matter passes rapidly through the earth from the equator towards each pole. This matter being porous, it not arrested in its passage by ordinary matter, but magnetic substances, in consequence of a peculiarity in their molecular structures oppose a resistance and are hence affected. Moreover, the vortex moves with the greatest facility in one particular direction; one of its ends being always turned towards the N. The pores of iron are regarded as valves, which open readily in one direction, but oppose the entrance of any substance in the opposite direction.

(1216) The theory of Descartes was adopted by Euler, who in his Letters (translated 1802) has thus set it forth: "Non-magnetic bodies are freely pervaded by the magnetic matter in all directions; loadstones are pervaded by it in one direction only; one of the poles being adapted to its admission, the other to its escape. But iron and steel, when rendered magnetic, fulfil this last condition; when they are not, it may be affirmed that they do not grant a free

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ERRATA.

Page 31,—7 lines from top, for "or" read "as."
„ 53,—22 lines from top, for "change" read "charge."
„ 81,—7 lines from top, for "small stars" read "a small star."
„ 84,—5 and 6 lines from top, for "change" read "charge."
„ 193,—4 lines from top, delete full stop after "induction" and let the sentence run on.
„ 206,—18 lines from top, for "Chalmers" read "Chambers."
„ 208,—8 lines from top, for "laying" read "lying."
„ 219,—2 lines from bottom, for "invested" read "inverted."
„ 239,—22 lines from bottom, for "eclectric" read "electric.
„ 240,—11 lines from bottom, after "W" insert "than."
„ 243,—14 lines from top, transpose the words "the" and "his.
„ 251,—15 lines from bottom, for "caps" read "cups."
„ 253,—15 lines from top, for "with" read "pith."
„ 264,—17 lines from bottom, for "enlose" read "enclose."
„ 269,—17 lines from bottom, for "to" read "with."
„ 294,—14 lines from bottom, insert "of" before "gold leaf."
„ 302,—12 lines from bottom, for "action" read "section."
„ 302,—12 lines from top, for "this" read "the."
„ 313,—11 lines from top, for "with" read "to."
„ 400,—19 lines from top, for "sulphuret" read "sulphur."
„ 420,—last line, for "Electro-phopiologiques" read "Electro-physiologiques."
„ 534,—18 lines from top, for "9·36" read "1·36."
„ 552,—20 lines from top, after "been" insert "that."
„ 574,—5 lines from top, after "and" insert "the best."
„ 744,—3 lines from bottom, for "conductor" read "condenser."
„ 770,—2 lines from top, for "filled" read "fitted."
„ 774,—8 lines from bottom, for "zinc" read "silie.

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	£	s.	d.		£	s.	d.
Glass Tube or Cylinder for exciting Electrical action when rubbed with a piece of warm Flannel or silk, page 17 .	0	1	6	to	0	5	0
Sealing Wax Cylinder for the production of Negative Electricity	0	5	0	...	0	10	0
Pith Balls and Insulated Stand for showing the phenomena of Positive and Negative Electricity by the attraction and repulsion of two pith balls . . . Fig. 1	0	3	6	...	0	10	0
Gilbert and Haüy's Electroscope, consisting of a light needle on brass stem, for showing the electric state of certain minerals . . . . . . Fig. 2	0	5	0	...	0	7	6
Canton's Electroscope as modified by Cavallo . Fig. 3	0	10	6	...	0	15	0
The Balanced Needle Electroscope . . . Fig. 4	0	12	0	...	0	15	0
Faraday's Electroscope, adapted for the lecture room Fig. 5	0	12	0	...	1	1	0
Sir William Snow Harris's Quadrant Electroscope . Fig. 6	1	1	0	...	1	11	6
Bennett's Gold Leaf Electroscope . . . Fig. 7	0	12	0	...	1	1	0
Singer's improved Gold Leaf Electroscope, with double insulation . . . . Fig. 8	0	12	0	...	1	5	0
Dr. Hare's Single Leaf Electroscope . . Fig. 9	0	17	6	...	1	10	0
Mr. Gassiot's Modification of the Single Gold Leaf Electroscope, by which its delicacy is increased so as to show an effect from a single pair of galvanic plates Fig. 172, page 308	2	2	0	...	3	3	0
Bohnenberger's Electroscope, with dry electric column, forming an instrument of wonderful sensibility . Fig. 10	2	2	0	...	5	5	0
Coulomb's Torsion Electrometer . . . Fig. 11	2	12	6	...	10	10	0
Sir William Snow Harris's Balance Electrometer . Fig. 12	4	4	0	...	8	8	0
Sir William Snow Harris's Hydrostatic Electrometer Fig. 13	8	8	0	...	10	10	0
Henley's Quadrant Electrometer, with graduated arc Fig. 72	0	7	6	...	0	10	0
Brass Cylinder mounted on insulated stand for experiments on Electricity . . . . . Figs. 14, 15, 18	0	10	6	...	0	15	0
Lane's Discharging Electrometer, shown in the figure as attached to a Leyden jar . . . . . Fig. 73	0	5	6	to	0	10	0

		£ s. d.		£ s. d.
Brass Sphere, on insulated stand, 3½ inches diameter	Fig. 15	0 11 6	to	0 15 0
Brass Cylinder and 2 Disks, all on insulated stands, for explaining the theory of Induction	Fig. 17	1 10 0	...	2 2 0
Pair of Wood Hemispheres, on insulated stands, for experiments on Induction	Fig. 19	0 10 0	...	1 1 0
Volta's Electrophorus, for obtaining the Electric Spark	Fig. 20	0 10 6	...	2 2 0
Biot's Apparatus to demonstrate the distribution of Electricity, and proving that it resides on the surface only	Fig. 27	2 2 0	...	3 3 0
Another Modification	Fig. 28	1 1 0	...	1 10 0
Franklin's Metallic Cup, on insulated stand, for similar purpose	Fig. 29	1 1 0	...	1 11 6
Muslin Bag, on stand, for above	Fig. 30	0 12 0	...	1 1 0
Another Modification	Fig. 31	[illegible] 12 0	...	1 1 0
A pair of Metallic Disks, 6 inches diameter, on insulated stands, to illustrate the principle of the Condenser	Fig. 32	1 10 0	...	2 2 0
Electric Condenser, consisting of two circular brass plates, one being insulated, the other attached to a jointed brass pillar. The insulated plate being connected with the cap of an Electroscope, on the removal of the uninsulated one, very minute quantities of Electricity are rendered visible		1 1 0	...	3 3 0
Volta Electric Condenser	Fig. 33	1 5 0	...	3 3 0
Gold-leaf Electroscope, mounted with Condenser	Fig. 34	1 11 6	...	2 12 6
Peclet's Electric Condenser, a very delicate instrument	Fig. 35	8 8 0	...	10 10 0
Cavallo's Multiplier	Fig. 36			
Cylinder Electric Machines. These consist of a Glass Cylinder, mounted in a mahogany frame, with brass conductor and clamp :—				
Size of cylinder 6 in. by 4 in.	Fig. 37	1 5 0	...	1 10 0
7 „ 5		1 10 0	...	2 2 0
9 „ 6		2 5 0	...	3 3 0
12 „ 9		5 5 0	...	8 8 0
14 „ 10		6 16 6	...	10 10 0
Plate Electric Machines, mounted in a mahogany frame, brass conductor, handle, and clamp, complete, of the most improved construction :—				
Size of plate 9 in. diameter. In wood case	Fig. 38	3 3 0	...	4 4 0
12 „ „		5 5 0	...	6 10 0
15 „ „		7 7 0	...	9 9 0
18 „ „		9 9 0	...	12 12 0
24 „ „		12 12 0	...	15 15 0
30 „ „		17 17 0	...	21 0 0
36 „ „		25 0 0	...	30 0 0
Larger machines made to order.				
Woodward's Improved Plate Electric Machines :—				
12 in.	Fig. 39	6 6 0	...	7 7 0
15 „		8 8 0	...	9 9 0
18 „		10 10 0	...	12 12 0
24 „		14 14 0	...	16 16 0
Mounted with a double plate, forming a very powerful machine :—				
12 in.		9 9 0	...	11 11 0
15 „		12 12 0	...	15 15 0
18 „		18 18 0	...	21 0 0
24 „		25 0 0	...	25 0 0

	£	s.	d.		£	s.	d.
Sir William Snow Harris's Electric Plate Machines, on mahogany open frames, with Positive and Negative Conductors:—							
18 in. . . . . . . Fig. 41	18	18	0	to	21	0	0
2 feet	22	0	0	...	25	0	0
3 "	45	0	0	...	50	0	0
4 "	75	0	0	...	80	0	0
Hydro-Electric Machines, consisting of a wrought-iron boiler, mounted on a carriage, with glass supports, detached conductor, &c., complete:—							
No. 1.	14	0	0	...	17	0	0
2	20	0	0	...	25	6	0
3	45	0	0	...	50	0	0
4	75	0	0		100	0	0
Glass Globe, on mahogany stand, mounted with stop-cock, brass caps and sliding wire, in air-tight collar of leathers, for experiments with the Electric spark in condensed air and in vacuo, &c. . . . . Fig. 43	1	11	6	...	2	2	0
Carved Head with Hair, to illustrate attraction and repulsion Fig. 45	0	3	6	...	0	5	6
Luminous Words formed on Glass by means of small spangles of tinfoil. On presenting the brass knob to the conductor of the machine, while a communication is made with the ground, the word is seen brilliantly illuminated . Fig. 46	0	7	6	...	1	1	0
Various devices are formed in this manner, as birds, stars, &c.	0	7	6	...	1	1	0
Painted Glass Plane, on stand, composed of different colours on which are formed figures as above, and when illuminated give a very beautiful effect.	0	12	6	...	1	10	0
Hand Spiral or Luminous Tube. This consists of two tubes, one inside the other; on the inner one are fixed the spangles, or small disks of tinfoil, in a spiral form, the extremities being mounted with brass balls. The effect produced is very pleasing	0	3	6	...	0	7	6
Barker's Revolving Spotted Tube, producing a still finer effect, motion being produced by the dispersion of Electricity from the five points . . . . . Fig. 47	0	12	6	...	0	15	0
Five Glass Tubes, of different colours, with circular disks of tinfoil, mounted on a mahogany stand. In the centre is a revolving brass arm, which transmits electricity to each tube in succession, producing a very fine effect . . .	1	10	0	..	1	15	0
Coloured Glass and Paper Plumes, to exhibit the repulsive action of similar electrified bodies	0	2	0	...	0	3	0
Insulated Stool, or Mahogany Stool on glass legs . Fig. 48							
12 inches square	0	12	0	...	0	15	0
15 "	0	17	6	...	1	0	0
18 "	1	10	0	...	1	12	6
Apparatus for Firing Spirits of Wine by means of sparks from the Electric machine . . . . . Fig. 49	0	7	6	...	0	12	0
Sturgeon's Apparatus for Firing Gunpowder, &c, by the Electric spark . . . . . . Fig. 83	0	8	6	...	0	12	0
Set of Three Bells, suspended on a brass rod or wire from the conductor of the machine, the centre one being in connexion with the ground. The attraction and repulsion is very well shown by the ringing of the bells . Fig. 50	0	7	6	...	0	10	0
Set of Five Bells on circular stand, four being insulated, and the fifth in connexion with the ground . . .	0	18	0	...	1	1	0

	£ s. d.		£ s. d.
The Gamut, or set of Eight Bells, mounted on a circular mahogany stand. In the centre is an electric fly, or whirl, carrying a clapper, which successively strikes each bell .	1 15 0	to	2 2 0
An admirable contrivance for illustrating Electrical Attraction and Repulsion. It consists of a glass plate on an insulated stand, round which is a flat brass ring, supported on small glass pillars. On the under part of the glass are strips of tinfoil, forming a broad margin and four radii, three or four very light glass globes being placed on the plate. The apparatus is connected as shown in the figure. The evolution of the balls is most striking and curious . Fig. 51	10 0	...	3 3 0
Electrical Orrery, or Planetarium. This little instrument illustrates the current of air which accompanies the discharge of electricity from points . . . Fig. 52	6	...	0 10 6
Electrical Water Mill. This little model, made in cardboard, is set in motion by directing a brass point, placed in the prime conductor of the machine, against the uppermost vane of the wheel . . . Fig. 53	0 15 0	...	1 1 0
Pair of Circular Metallic Plates, the bottom one being on an adjusting stand, the upper one suspended from the prime conductor. Small figures of pith being placed between them, attraction and repulsion is shown in a very amusing manner . . . . . . Fig. 55	10 6	...	1 1 0
Pith Figures of Men and Women . . . Fig 55	1 0	...	0 2 6
Small Pail or Bucket, showing the influence of a current of Electricity on a stream of water . . . Fig. 56	5 0	...	0 7 6
Pith Ball Stand, or Glass, in which are placed some pith balls, illustrating Electrical attraction and repulsion. .	4 0	...	0 7 6
Glass Tumbler, on stand, for showing attraction or repulsion by means of little pith balls . . . Fig. 57	6 6	...	0 8 6
Pith Balls, per doz.			
Electrical Spider. This being supported by a thread from the conductor, the legs are attracted by a brass ball and repulsed by a point	1 0	...	0 1 6
Electrical Swing. This little apparatus is dependent upon Electric attraction and repulsion . . . Fig. 58	12 0	...	0 15 0
See-saw. This is another electric toy to illustrate the same law	15 0	...	1 1 0
Carved figures in cork, representing Neptune, a Mermaid, &c. These being set to float in an insulated basin, and the water electrified, are attracted by a metallic wire being presented to them	0 6 0	...	0 7 6
Apparatus for the ignition of phosphorus by the action of a current of Electricity on the flame of a candle . Fig. 59	0 15 0	...	1 1 0
Exhausted tube for showing the resistance which the presence of the atmospheric air offers to the transmission of Electricity. When partially exhausted the fluid passes in the form of a beautiful blue light closely resembling the Aurora Borealis . . : . . Fig. 54	0 15 0	...	3 3 0
Luminous or Exhausting Flask, with screw and valve, for showing the same phenomena	0 8 6	...	0 12
Glass Bell Receiver, mounted with brass cap and a light sliding rod. Brass plate on foot with stop-cock for experiment with Electric light . . . . Fig. 60	2 2 0	...	3 3 0

Item	£	s.	d.		£	s.	d.
Brass syringes for exhausting tubes and flasks	0	7	6	to	0	15	0
Electrical or Leyden Jars, with mahogany covers and coated with tinfoil:— Fig. 66							
½ pint	0	4	6	...	0	5	6
1 „	0	6	0	...	0	7	6
1½ „	0	7	6	...	0	9	0
1 quart	0	8	6	...	0	10	0
3 pints	0	10	6	...	0	12	0
2 quarts	0	15	0	...	0	17	0
1 gallon	1	1	0	...	1	4	0
Medical Electric Jars so arranged as to retain the charge for a considerable period. Fig. 67	0	7	6	...	0	10	6
Leyden jars mounted on the plans of Barker, Lockey, and Harris. Figs. 68, 69, 70	0	7	6	...	1	1	0
Spotted or Diamond jars. Fig. 81	0	6	0	...	1	1	0
Two Leyden Jars mounted for illustrating the theory of Franklin. Fig. 79	0	10	6				
Leyden Jars mounted as shown in Fig. 80	0	12	0	...	0	18	0
Leyden Jar with moveable coatings for illustrating the fact that Electricity resides only on the surface of the glass	0	12	0	...	0	18	0
Faraday's Electric Jar with wire-gauze mounting, for illustrating the action of the Leyden phial	0	14	0	...	1	1	0
Electrical Sportsman.—This popular experiment consists of a carved figure which is fixed on to the same board with a Leyden jar; from the latter proceed two wires in opposite directions and of different lengths. The longer and most distant carries two small pith birds supported by two threads, and the shorter wire is terminated with a small ball touching the muzzle of the sportsman's gun. On charging the jar the birds rise, and on the discharge they drop as if shot	0	18	0	...	1	11	6
Electric Batteries, consisting of a combination of glass jars mounted with brass balls and wires, in mahogany tray Fig. 76	1	1	0	...	10	10	0
Electric Batteries mounted on the plan of Sir Wm. Snow Harris. Fig. 77	2	2	0	...	20	0	0
Magic Picture for giving slight shocks. It consists of a pane of glass coated with tin-foil and acts the same as a Leyden jar	0	7	6	...	0	10	0
Discharging Rod with insulated glass handle. Fig. 91	0	2	6	...	0	5	0
Superior jointed, ditto	0	7	6	...	0	15	0
Electric Directors with glass handles, useful for medical purposes	0	3	6	...	0	5	0
Director for administering Electricity to the eye	0	2	6	...	0	5	6
Director for administring Electricity to the ear	0	3	6	...	0	5	6
Luminous Discharging Rod consisting of a bent tube mounted with handle in the centre and brass ball at each end, these latter are connected by means of a rusty iron chain; when discharging a Leyden jar it becomes beautifully illuminated	0	7	6	...	0	12	0
Cuthbertson's Universal Discharger, the forces being estimated by grain weights. Fig. 74	2	2	0	...	2	12	6
Henley's Universal Discharger, for passing the shocks through various objects, deflagrating metals, &c., &c. Fig. 75	1	1	0	...	1	11	6
Leyden Jar mounted with brass plate and small cannon Fig. 85	0	15	0	...	1	1	0

Article	Fig.	£	s.	d.		£	s.	d.
Two Leyden Jars mounted as shown	Fig. 86	0	12	0	to	1	1	0
Kinnersley's apparatus for showing the rarefaction which takes place in air when an Electric spark passes through it	Fig. 88	1	1	0	...	1	10	0
Small Jars, mounted with valve, to exhibit the Leyden vacuum	Fig. 89	0	7	6	...	0	10	0
Long glass tube, mounted on foot, to exhibit what is popularly known as the Falling Star		0	12	0	...	2	2	0
Mahogany Model called the Lightning House, showing the importance of lightning conductors	Fig. 90	0	18	0	...	1	1	6
Brass Cannon mounted on brass carriage, to be charged with oxygen and hydrogen gas, and fired by the Electric discharge	Fig. 91	0	17	0	...	1	1	0
Brass Cannon on wood carriage		0	10	6	...	1	1	0
Electric Pistol to be charged and fired similar to the cannon		0	7	6	...	0	10	0
Brass Electric Cannon to fire gunpowder	Fig. 91	0	5	6	...	0	10	0
Electric Mortar or Bomb, made in hard wood or ivory and charged with fulminating silver		0	5	0	...	0	7	6
Electric Fire House. In the inside of this little model of a house is place a small portion of cotton wool saturated with spirits of wine—on discharging through it a Leyden jar it is set on fire		0	13	0	...	0	18	0
Professor Hare's Apparatus for deflagrating metallic wires	Fig. 92	1	1	0	...	1	10	0
Richman's Arrangement to show the quality of the two Electricities on the inner and outer surfaces of the Leyden jar	Fig. 93	1	11	6	...	2	2	0
Sir Wm. Snow Harris's Electro Thermometer	Fig. 94	1	11	6	...	2	2	0
Sir Wm. Snow Harris's Discharging Electrometer	Fig. 95	1	5	0	...	1	10	0
Harris's Unit Jar Electrometer, for measuring the quantity of Electricity conveyed into a battery or large Leyden jar	Figs. 96, 97	1	1	0	...	2	2	0
Faraday's Induction Apparatus	Fig. 98							
Cards mounted with gold-leaf to prove that an Electric explosion will not leave a good conductor to fall upon bodies out of that line	Figs. 102, 103	0	2	0	...	0	2	6
Electric Exploring Conductors and apparatus for studying atmospheric Electricity, made to order	Fig. 110							
Noad's String Box mounted with a Lane's discharger for experiments with the Electric kite	Fig. 113	2	2	0	...	3	3	0
Electric Kite String having a metallic wire worked into it								
Volta's Atmospheric Electrometer	Fig. 114							
„ Spark Measurer	Fig. 115	3	3	0	...	4	4	0
Gold-leaf Electroscope as used at the Kew Observatory	Fig. 116	2	2	0	...	3	3	0
The "Distinguisher," as used also at the Kew Observatory	Fig. 117	2	2	0	...	3	3	0
The Induction Electrometer of M. Peltier.		3	3	0	...	4	4	0
Lightning Conductors made and fixed on the most approved principles.								
Cavallo Pith Ball Electroscope, used for experiments on Atmospheric Electricity		0	12	0	...	0	15	0

	£ s. d.		£ s. d.
Thunder House, being a mahogany model to explain the use of lightning conductors . . . . Fig. 120	0 7 6	to	0 12 0
Mahogany Model of an Obelisk, to illustrate the same thing .	0 10 0	...	0 15 0
Small Model, to illustrate the use of conductors as applied to ships . . . . Fig. 121	2 2 0	...	4 4 0
Apparatus to illustrate the fact that pointed bodies discharge the electricity of the clouds without attracting them . Fig. 122	1 1 0	...	2 2 0
Atmospheric Electric Warning Bell. An open mahogany frame represents the roof of a house, through which passes an insulated lightning rod; one of the two bells communicates with the floor, the other with the rod; a thread of silk sustains the clapper, which rings the bell when the thunder cloud passes over the rod. (A large machine may be made to represent the real cloud) . . .	1 15 0	...	2 2 0
Models to show Sir Wm. Snow Harris's plan of applying lightning conductors to ships.			

The following materials, parts, portions, &c., of apparatus are required for matters of experiment:—

Brass Chain, per doz. yards 0 3 0

Brass Electric Balls, with similar screw-hole for attaching to wire—

¼	⅜	½	¾	1	1¼	1½	1¾	2 inches diameter
/3	/3	/3	/6	/9	1/	1/6	2/6	

Brass Wire, taped, with screw to fit the balls—

6	9	12 inches long.
/4	/6	/9

		£ s. d.		£ s. d.
Tinfoil	per lb.	0 2 6		
Superior Amalgam for Electric Machines .	per box	0 1 0	...	0 2 0
Brass Conductors for small Electric Machines.		0 4 6	...	0 10 0
Glass Solid Rod	per lb.	0 1 6		
Glass Stool Feet	each	0 1 0	...	0 2 6
Glass Handles for Discharging Rods .	"	0 1 2	...	0 1 6

Glass Cylinders for Electric Machines—

6 by 4	7 by 5	9 by 6	12 by 9	14 by 10
2/6	4/	6/	10/	14/ each

Circular Glass Plates, with hole drilled in centre for fitting up Plate Electric Machines—

9	12	15	18	24	30 inches
6/	12/	21/	30/	60/	100/ each

Plain Glass Jars, for coating with tinfoil—

½ pint	1 pint	1½ pint	1 quart	3 pints	1 gallon
1/	1/6	1/9	2/	3/	4/6 each

GALVANIC APPARATUS AND MATERIALS.

	£ s. d.		£ s. d.
Pair of Platina and Zinc Plates, to illustrate the formation of a galvanic circuit . . . . Fig. 130	0 12 0	...	1 10 0
Simple Galvanic Arrangement, consisting of a cylinder of zinc and double cylinder of copper, which holds the dilute sulphuric acid . . . . . Fig. 133	0 10 6	to	1 1 0

	£ s. d.	£ s. d.
Volta's Galvanic Pile, consisting of one hundred pairs of zinc and copper disks 2 in. diameter, supported between three mahogany pillars, on stand . . . Fig. 135	1 10 0 to	2 2 0
De Luc's Electric Column . . . . Fig. 136	1 11 6 ...	3 3 0
Electroscope, with moveable leaves . . . Fig. 137	1 11 6 ...	2 2 0
Faraday's Apparatus for showing the Phenomena of an Electric Current independent of the contact of dissimilar metals	0 10 6 ...	0 15 0
Pairs of round Zinc and Copper Plates, soldered together, two inches diameter, to form with moistened cloth the pile of Volta, per dozen	0 5 0	
Silver and Zinc Wires soldered together in pairs for placing in small glasses with dilute acid solution, forming the "couronne des tasses" of M. Volta, per dozen . .	0 6 0	
Zinc and Copper Cylinders in Glass Jars to form a Water Battery, properly insulated and arranged, per 100, from	2 10 0	
Mica Battery . . . . . Fig. 138		

Galvanic Arrangement or Battery, termed Cruikshank's, consisting of a series of copper and zinc plates soldered together, and cemented into a mahogany trough. Chiefly used for medical purposes.

	£ s. d.
With 50 pair of plates, $1\frac{3}{4}$ inch . .	1 8 0
" 100 " — " . .	2 15 0
" 150 " — " . .	4 4 0
" 200 " — " . .	5 5 0
" 50 " $2\frac{1}{4}$ " . .	1 16 0
" 50 " $3\frac{1}{2}$ " . .	2 10 0
" 50 " $4\frac{1}{2}$ " . .	3 10 0

	£ s. d.
Dr. Wollaston's Arrangement, consisting of twelve pair of 4-inch plates in porcelain trough	2 12 6
Dr. Hare's Arrangement . . . . Fig. 144	
Van Melsen's Battery . . . . Fig. 146	

Professor Daniell's Constant Battery:—

	£ s. d.
1 Cell, 6 inches high . . . Fig. 151	0 6 6
1 " 12 " "	0 12 0
1 " 18 "	0 17 6
A Set of six, 6 inches, in mahogany frame . Fig. 152	2 10 0
" 12 " " . .	4 4 0
" 18 " " . .	6 6 0

Smee's Chemico-Mechanical Batteries, consisting only of zinc and platinized silver plates in porcelain jar, requiring only one fluid—viz., dilute sulphuric acid. This battery, though not so powerful as Grove's, Bunsen's, or Callan's, possesses the great advantage of simplicity . . . Fig. 154

	£ s. d.
The Platinized Silver Plate . . . 2 by 4 inches .	0 8 6
" " . . . 3 by 5 " .	0 10 6
" " . . . $3\frac{1}{2}$ by $5\frac{1}{2}$ " .	0 14 6

These batteries are well suited for electrotyping purposes.

	£ s. d.
A series of six pair, (size of Platinized Silver Plates 3 in. by 5) in gutta percha or glass cells, the whole of the plates being raised from or immersed into the cells by means of a windlass. Well adapted for the lecture table . . Fig. 155	4 14 6
Set of Ten, well adapted for blasting . . .	7 7 0

Item	£	s.	d.	£	s.	d.
Grove's powerful Galvanic Batteries, in glass cells and mahogany tray. Size of Platina Plates, 6 by 3.						
Set of 3 „	3	3	0			
„ 4 „	4	4	0			
„ 6 „	6	6	0			
Set of 10 pair, in glass cells and wood tray.	10	10	0			
10 sets of the above, making 100 pair of plates, and constituting a most powerful battery, exhibits the Electric light in a very satisfactory manner.						
Improved Carbon, or Bunsen's Battery . . Fig. 161						
A single element, consisting of a carbon cylinder, porous pot, and zinc plate in glass jar	0	6	0			
Series of 10 elements	3	0	0			
„ 20 „	6	0	0			
The Callan, or Manooth Battery. This form of battery consists of a cast-iron cell, in which is a porous pot containing the zinc plate. The cast-iron cell is charged with nitric acid, and the porous one with dilute sulphuric. This forms an economical battery, of about the same power as Grove's.						
A single cell	0	6	0			
A series of 10, in strong wood tray . . 4 in. sq.	3	3	0			
A single cell	0	8	(			
A series of 10, in strong wood tray . . 8 in. sq.	4	14	(			
Dr. Leeson's Improved Battery, consisting of 10 pair of copper and zinc plates, arranged in a mahogany trough Fig. 164	3	10	0			
Grove's Gas Battery . . . . . Fig. 165						
Set of four elements arranged in series . . .	4	4	0			
Set of six	6	6	0			
Grove's Gas Battery . . . . . Fig. 169						
Single Element	2	2	0			
Wheatstone's Rheostat, an instrument for measuring and regulating the resistance offered to the Electric current by passing through various lengths of wire :—						
For great resistances . . . . Fig. 170	3	13	6 to	4	14	
For small resistances . . . . Fig. 171	8	8	0 ...	10	10	
Wheatstone's Series of Resistance Coils for measuring the resistance of long telegraph wires, or imperfectly conducting liquids	2	2	0 ...	5	5	0
De la Rue's Discharger for readily submitting different charcoal points and metals to the influence of the galvanic battery . . . . . . Fig. 173	2	2	0 ...	3	3	0
Arrangement to show the heating effects of the galvanic current, consisting of a spiral platina wire in a glass tube Fig. 174	0	12	0 ...	1	10	0
Contrivance by which different lengths of the same platina wire may be submitted to the galvanic current inclosed in a glass tube	1	5	0 ...	2	2	0
Apparatus consisting of a glass globe mounted with stop-cock and sliding forceps for showing the Electric light in vacuo . . . . . . Fig. 176	1	17	6 ...	3	3	0
Duboscq's Electric Lamp, a contrivance for regulating and keeping constant the Electric light produced by the charcoal points.						
Deleuil's Modification as shown in . . Fig. 177, 178						
Oersted's Apparatus for showing the deflection of the magnetic needle by a copper wire transmitting an Electric current round it . . . . . Fig. 184	0	10	6 ...	1	1	0

	£	s.	d.		£	s.	d.
Improved form so arranged that the wire transmitting the Electric current may be carried in a parallel direction entirely round a freely suspended magnetic needle .	1	1	0	to	1	11	6
Galvanometer consisting of a rectangular coil of insulated copper wire, containing a magnetic needle suspended by a point, mounted on a mahogany board . .	0	10	6	...	1	1	0
Torsion Galvanometer on the principle first described by Dr. Ritchie . . . . . Fig. 185	0	12	0	...	1	1	0
Improved Torsion Galvanometer with astatic needle as recommended by Professors Cumming and Nobili. Divided metal ring, mounted on a mahogany board, with levelling screws and glass shade	2	2	0	...	4	4	0
A more delicate instrument on brass stand, with moveable coil of very fine wire, adjusting screws, divided circle, and glass shade . . . . . . Fig. 186	5	5	0	...	8	8	0
The Sine Galvanometer for the determination of the intensity of strong Electric currents . . . Fig. 187	5	0	0	...	7	0	0
Tangent Galvanometer . . . Fig. 188	7	7	0	...	15	15	0
Cumming's Gold-leaf Galvanometer. It consists a slip of gold-leaf enclosed within a glass tube, the gold-leaf forming part of the circuit is attracted or repelled by the poles of a magnet	1	11	6	...	2	2	0
Sturgeon's Gold-leaf Galvanometer and dry Electric pile . . . . page 335							
Iremonger's Hydrostatic Galvanometer . . page 335							
Apparatus for the decomposition of water by the galvanic battery :—with 1 tube . . . . Fig. 193	0	12	0	...	1	1	0
,, with 2 tubes	0	14	0	...	1	11	6
Apparatus for decomposition of neutral salts . Fig. 194	0	5	0	...	0	10	6
Ditto, with two glass tubes . . . Fig. 195	0	7	6	...	0	10	0
Faraday's Rectangular Glass Trough, or cell for exhibiting Electro-chemical decompositions . . Fig. 196	0	10	0	...	0	15	0
Sir H. Davy's Apparatus for the Electro-reduction of the alkaline metals	1	1	0	...	1	10	0
Golding Birds arrangement for obtaining amalgams of the alkaline metals, with a galvanic current of a single pair of plates . . . . . . Fig. 197	0	14	0	...	1	1	0
Faraday's apparatus to illustrate the fact that water may act as a pole in a galvanic circuit proved by the decomposition of sulphate of magnesia . . . . Fig. 198	0	12	0	...	0	18	0
Faraday's Volta-Measurers for measuring the quantity of Electricity passing through it. This is only adapted for feeble Electric forces . . . . . Fig. 207	1	1	0	...	1	10	0
Faraday's Volta Electrometer, with larger Electrodes for decomposition of water by a more powerful galvanic current Fig. 202	1	10	0	...	5	0	0
Pair of Platina Disks or Plates on insulated columns for the decomposition of the alkalies by galvanism . Fig. 200	1	10	0	...	2	10	0
Apparatus for obtaining by the aid of the galvanic fluid sulpher, sulphate of baryta, &c., in a crystalline state .							
Daniell's Apparatus for experiments on the Electrolysis of secondary compounds . . . Fig. 210							

ELECTRO-METALLURGY OR ELECTROTYPE.

Electro-Metallurgy, or Electrotype, being the art of depositing from their solutions various metals, as gold, silver, copper, &c., in the metallic form.

Single cell apparatus in porcelain or glass jar .	Fig. 211	0 3 6 to 0 10 6
Apparatus in mahogany trough requiring neither acid or mercury	Fig. 213	0 12 0
Battery Apparatus	Fig. 212	
Smee's Single Cell batteries of a form expressly adapted for Electrotype operation :—		
No. 1. size of Platinized silver plate 4 by 2		0 8 6
2. „ „ 5 by 3		0 10 6
3. „ „ 5½ by 3		0 14 6
4. „ „ 6 by 4		0 17 6
Large Compound Acid Battery, the zinc plates being 10 in. by 6, surrounded by copper in stone-ware cells and wood frame. A series of four		5 5 0
Decomposing Troughs	Fig. 212	
Made in ash properly cemented inside.		
5 inches long by 4½ inches deep . . .		0 7 0
8 „ 6 „ . . .		0 10 0
12 „ 10 „ . . .		0 14 0
18 „ 12 „ . . .		1 0 0
Large sizes to order.		
Decomposing Troughs made in mahogany, with more finished mountings		
9 inches by 6 inches		0 15 0
12 „ 10 „		1 1 0
Electrotype Apparatus in which neither acid or mercury is used (pure zinc, sulphate of copper, and muriate of ammonia being the materials employed) .	Fig. 213	0 12 0
Horizontal Decomposing Trough for taking off and copying copper-plates. By this arrangement furrows on the surface of the newly formed plate are more readily prevented. Size 10 by 8	Fig. 214	1 0 0
Larger sizes to order.		
Apparatus for producing six Electrotypes at the same time	Fig. 215	1 1 0

APPARATUS FOR ELECTRO-GILDING AND SILVERING.

Single Cell Apparatu. consisting of a square porcelain or glass cell, porous pot, and zinc plate	0 3 6 to 0 10 0

(The best form of Apparatus for gilding or silvering is the battery and decomposing cell similar to Fig. 212. The trough being made in glass or stone-ware, and the battery consisting of a series of plates in place of a single pair.)

	£ s. d.	£ s. d.
Glass Decomposing Troughs with metal bars and binding screws to support the plate of gold or silver and also the articles to be coated.	0 10 0 to	1 1 0
Large sizes for manufacturing purposes made in stone-ware to order.		

BATTERIES FOR ELECTRO-GILDING OR SILVERING.

(For small operations either Smee's or Daniell's arrangements are the best, but for manufacturing purposes larger plates of copper and zinc are used, see Compound Acid Battery.

In place of the galvanic battery the Electro-Magneto machine is now much used. One mounted for this purpose with a 12 inch Compound Magnet of 6 bars . . . 10 10 0 ...15 0 0

Gassiot's apparatus for producing Nobili's coloured rings by the decomposition of acetate of lead on a polished steel plate. 0 10 6

SUNDRY MATERIALS FOR CARRYING ON GALVANIC OR ELECTROTYPE EXPERIMENTS.

Porous Cells of superior quality :—

	Round.	s.	d.	Flat.	s.	d.
Size	2½ by 1½ ...	0	4	3½ by 2	0	6
	3½ by 1½ ...	0	5	4½ by 4	0	10
	4½ by 2 ...	0	6	5½ by 3½	1	0
	6 by 2 ...	0	9	4 by 4 ⅞ wide	1	0
	9 by 2 ...	1	0			
	12 by 2 ...	1	6	7 by 7		
	18 by 2 ...	2	6	12 by 12		

		£ s. d.	£ s. d.
Binding Screws of various forms.	each	0 0 6 ...	0 2
Brush for applying plumbago to moulds		0 1 0	
Brush for bronzing electrotypes		0 1 0	
Scratch Brush for cleaning articles to be gilded or plated.		0 1 0	
Copper Sheet	per lb.	0 1 8	
Copper Wire	,,	0 1 8	

Copper Wire, covered with either cotton or silk in a very superior manner, the perfect insulation of which may be depended on. For electro-magnetic experiments, construction of coils, and telegraphic instruments. Other sizes can be had, but the following are those generally in stock :—

		Covered with Cotton.	Covered with Silk.
12	per lb.	2 6	
14	,,	2 6	
16	,,	2 6	7 0
18	,,	2 6	7 6
20	,,	2 10	8 0
22	,,	3 0	
24	,,	4 0	10 6
26	,,	4 6	
28	,,	5 0	
30	,,	6 0	13 6
32	,,	7 0	15 0
35	,,	11 0	19 0

		£	s.	d.		£	s.	d.
Copper, Sulphate	per lb.	0	0	8				
Clichee Metal, for moulds	„	0	3	6				
Carbon Bisulphuret	„	0	3	0				
Muriatic Acid	„	0	1	0				
Nitric Acid	„	0	1	6				
Sulphuric Acid	„	0	0	3				
Carbon Points, for producing electric light with galvanic battery.		0	1	0	to	0	2	0
Gold, pure Sheet and Wire	per dwt.	0	5	6				
Gold Oxide, in bottles.		0	7	6	...	1	1	0
Gold Cyanide Solution	per pint	0	16	0				
Platina, Sheet and Wire	per oz.	1	10	0				
Platina Foil	„	1	12	0				
Potassium Cyanide	per lb.	0	3	6	to	0	5	0
Potash, Yellow Prussiate	„	0	2	0				
Phosphorus	per oz.	0	0	6				
Phosporus Solution in Sulphuret of Carbon	„	0	1	0				
Plumbago	„	0	0	6				
Gutta Percha, for making moulds	per lb.	0	3	0				
Silver, pure Sheet and Wire	per oz.	0	8	0				
Silver Cyanide Solution	per pint	0	10	0				
Silver Oxide, in bottles, 3*s*. 6*d*. and 6*s*. 6*d*.	per oz.	0	7	0				
Stearine	per lb.	0	2	0				
Wax, White or Virgin	„	0	3	0				
Zinc, Commercial	„							
Zinc, Pure	„	0	1	6				
Zinc, cast in Rods or Plates	„	0	1	6				
Zinc, Sheet, cut in Plates	„	0	1	6				

Improved Moulds for Electrotyping, made of Clichee Metal and of Prepared Gutta Percha. These Moulds are so perfect, that they produce Electrotypes equal in beauty and perfection to the original medals.

The Mudie National Medals. A grand series of Forty English Medals, published by James Mudie, Esq., commemorating the success and valour of the British arms in the Peninsula. They consist of seventy moulds, some of the obverses being duplicate :—

In Clichee Metal, £5, or 1*s*. 6*d*. each.
In Gutta Percha, £1 1*s*., or 4*d*. each.
Descriptive Catalogue of the series, 6*d*.

Dassier's Medals of the Kings and Queens of England, from William I. to George II.

		£	s.	d.
The set of 70 Moulds in Gutta Percha		1	1	0
Moulds in Clichee Metal	each	0	1	6
Moulds in Gutta Percha	„	0	0	4

	£ s. d.	£ s. d.
The Grand Series of 141 Medals struck at the National Mint of Paris by order of Napoleon Bonaparte, commemorating the most remarkable battles and events during his dynasty. 212 Moulds :—		
In Clichee Metal	10 10 0	
In Gutta Percha	5 0 0	

Cost of the single Moulds according to the diameter.

A great variety of Clichee and Gutta Percha Moulds from interesting Medals, both English and Foreign :—

	Clichee Metal.	Gutta Percha.
1⅜ inch diameter .	1s. 3d.	
1⅞ „ .	1 6	0s. 4d.
2 „ .	2 6	0 6
2½ „ .	3 0	0 9
3 „ .	4 0	1 0
3½ „ .	5 0	2 0

	£ s. d.	£ s. d.
Knight's Preparation for Bronzing Electrotype Medals. This being applied in the form of a powder, instead of a liquid, as is usually the case, does not injure or clog in the slightest degree the sharpness of the finest line. In bottles, with directions for use	0 2 0	

APPARATUS FOR MEDICAL PURPOSES.

	£ s. d.	£ s. d.
Knight's Arrangement of the Medical Coil Machine. It consists of a horizontal primary and secondary coil, above which is a small vibratory armature. With battery, medical directors, &c., the whole enclosed in a very neat and portable mahogany case, with lock and key	3 13 6	
More powerful Apparatus, on a similar construction, with two batteries and water regulator, in handsome mahogany case.	7 17 0	
Dr. Golding Bird's Electro-Magnetic Coil Machine . .		

The advantage offered by this arrangement of the Coil Machine, is the having a secondary as well as a primary coil, at the same time that the electric current passes in one direction only. In all Electro-Magnetic Machines with vibrating armatures, used for medical purposes, the current of electricity is not continuous in one direction, but the same wire is alternately positive and negative. This is readily proved by the galvanometer or by chemical decomposition. On this account, therefore, however useful the vibrating machine is when merely required as a stimulant, it is likely to fail in its effects when brought into use in many forms of paralysis, in consequence of the operator not being able to transmit the positive current in the direction of the nervous ramifications.

	£ s. d.	£ s. d.
In mahogany case, with conductors . . .	4 4 0	
Noad's Medico-Electro-Dynamic Coil Machine, constructed with the object of regulating to the greatest nicety, not only the strength, but also the frequency in the direction of the shocks. (See detailed description, to be had of the publishers.)	10 10 0	
Magneto-Electric Machines for Medical Purposes . . (See Magneto-Electric Apparatus.)	5 5 0 to	12 0 0

MEDICAL DIRECTORS.

	£	s.	d.	£	s.	d.
Plain Sponge Directors	0	3	6 to 0	7	6	
Directors for applying the Current to any particular part, such as the ear, teeth, nerves, &c.	0	3	6 ... 0	10	0	
Directors for applying the Current to various parts of the body	0	3	6 ... 0	10	0	
Dr. Radford's Uterine Director	0	12	6			

THERMO-ELECTRIC APPARATUS.

	£	s.	d.	£	s.	d.
Seebech's Rectangular Frame of Bismuth and Antimony, inclosing a magnetic needle on a centre, which is deflected on the application of heat . Fig. 233	0	8	6 ...	0	12	6
Pouillet's Arrangement, consisting of a short cylindrical bar of bismuth, with conducting wires for completing the electric current in either direction . Fig. 234	0	15	0 ...	1	1	0
Thermo-Apparatus, consisting of a frame, the upper part composed of copper, the lower of bismuth, with a magnetic needle on centre, which is deflected on the application of heat . Fig. 235	0	10	0 ...	1	1	0
Thermo-Rotating Rectangular Frames, composed of platina and silver-wire, mounted on a horse-shoe magnet, with brass foot and lamp, the flame of which causes the frames to revolve . Fig. 236	1	1	0 ...	1	10	0
Melloni's Thermo-Electric Battery, consisting of a series of small bars of antimony and bismuth soldered alternately together, mounted on stand, with binding screws Fig. 238	1	5	0 ...	1	11	6
Melloni's Thermo-Electric Apparatus, for his experiments on the radiant heat of various bodies, their power of emitting and absorbing it, &c.	0	0	0 ...	30	0	0
Lock's Thermo-Electric Battery, consisting of a series of bars of antimony and bismuth fixed in a metallic cylinder, leaving only the extremities of the bars exposed. The instrument is put in action by placing it in a vessel of ice, and then laying the hot iron plate on the top . Fig. 240	3	3	0 ...	5	5	0
Professor Cumming's Stellar-Form Thermo-Electric Composite Battery, composed of forty pairs of iron and copper wires, formed in radial lines on a circular cardboard Fig. 241	2	12	6 ...	3	3	0
Professor Dove's Composite Thermo Battery for constant currents . Fig. 242	4	4	0 ...	5	5	0
Van der Voort's Thermo-Electric Battery, consisting of eighteen pairs of antimony and bismuth united alternately and fixed in a mahogany box by plaster of Paris. To use it, the bottom is placed in a freezing mixture, and boiling oil or water placed on the top . Fig. 243	2	12	6 ...	3	3	0
Watkins's Thermo-Electric Pile, consisting of a number of square antimony and bismuth plates alternately soldered together and mounted in a frame, with the upper and lower junctions of the metals exposed . Fig. 244	4	4	0 ...	5	5	0

	£ s. d.	£ s. d.
Peltier's Thermo-Electric Hygrometer, consisting of a series of slender bars of antimony and bismuth, arranged alternately in the form of a crown, and united in pairs. A platina disk containing water is placed on the top of the compound wires, the evaporation of the water causes a reduction of temperature, which develops the electric current, shown by the deflection of a galvanometer . Fig. 245	0 10 6 to	1 1 0

ELECTRO-MAGNETIC APPARATUS,

DESCRIBED IN

NOAD'S MANUAL OF ELECTRICITY.

PART II.

MAGNETIC APPARATUS. £ s. d.

Comprising the various instruments for illustrating the phenomena, and carrying on investigations, in this important and interesting branch of Science.

Bar Magnets.—These are used for illustrating the Laws of Polarity, Attraction, and Repulsion, exhibiting the magnetic curves, and requisite for carrying on various investigations:—

A pair with soft iron armatures in sliding mahogany box—Fig. 277

6in.	8in.	10in.	12in.	16in.	18in.
4/	5/6	7/6	10/6	14/	21/

Horse-shoe Magnets. This is the commonest form of the Magnet. The poles are brought near together, and furnished with a soft iron armature or keeper, when it is capable of supporting several times its own weight:— Fig. 291

2	3	4	5	6	7	8	9	10	12 inches
/5	/6	/8	1/	1/6	2/6	3/	4/	5/	7/ each.

Compound Horse-shoe Magnets.—When several are placed together, and properly secured by bolts, their power for sustaining weights and exhibiting the various phenomena of Magnetism is greatly increased:—

Compound Magnets.—6 inches long—

3 bars	4 bars	6 bars
12/	16/	24/

Compound Magnets.—8 inches long—

3 bars	4 bars	6 bars
18/	24/	36/

Compound Magnets.—10 inches long—

3 bars	4 bars	6 bars
24/	32/	48/

Compound Magnets.—12 inches long—

3 bars	4 bars	6 bars
28/	37/	58/

Any other sizes made to order.

Compound Horse-shoe Magnets are frequently made of an odd number of bars, the centre one being the longest, the two on each side shorter, and the two next still shorter, forming a step-like appearance at the poles; for many purposes this arrangement is very convenient, especially in charging other magnets:—

	£	s.	d.
8-inch Magnet of 5 bars	1	10	0
10-inch ditto	2	2	0
12-inch ditto	2	12	6

	£ s. d.	£ s. d.
Logeman's Magnets (*Vide* Noad's Manual, 81)		
Single.—Logeman's Horse-shoe Magnets :—		
No. 1. 6 inches long, supporting 25 lbs.	1 5 0	
2. 8½ „ „ „ 45 lbs.	2 2 0	
Compound.—Logeman's Horse-shoe Magnets of 3 bars :—		
No. 1. 9 inches, supporting 86 lbs.	5 5 0	
2. 13 „ „ 150 lbs.	10 10 0	
Loadstone, or Natural Magnet, cut into small flat pieces which exhibit polarity	0 1 6 to	0 10 0
Loadstone, mounted with soft iron sides and poles, and provided with an armature, by which its power of sustaining weights is greatly increased . . . Fig. 266	1 10 0 ..	10 10 0
Scoresby's Magnets; these are formed of thin magnetized steel plates, the whole being bound firmly together	0 15 0 ..	2 2 0
Circular or Stella-form disks of soft iron, for the distribution of Magnetism	0 2 0 ..	0 7 6
Half-links of soft iron, to illustrate the inductive principle by which pieces of soft iron are rendered temporarily magnetic while in contact with the permanent magnet . . per doz.	0 3 6 ..	0 7 6
Robinson's Y-shaped soft iron armature, for exhibiting the neutralization of induced magnetism, when both ends of the fork are in contact with the poles of the Horse-shoe Magnet. The attractive power of the lower limb is destroyed, and no longer suspends a piece of soft iron	0 2 0 ..	0 5 0
Iron armatures, in the form of a cross, for suspending soft iron balls, exhibiting a pleasing set of experiments	0 2 6 ..	0 7 6
Pieces of soft iron of various forms for exhibiting Magnetic experiments	0 0 3 ..	0 2 0
Magnetic Toys, to illustrate in a popular manner Magnetic attraction and repulsion, when placed in or on the surface of water :—		
Two Fish in box	0 0 6 ..	0 1 6
Two Ducks	0 1 0 ..	0 2 0
Ships . . . from	0 1 0 ..	0 3 0
Magnetic Steel Needles, with hard brass centres, and of various lengths for experiments :—		

2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.
1/3	1/9	2/0	3/0	4/0	5/0	6/0

	£ s. d.	£ s. d.
With Agate centres		
Stand with brass foot and fine steel point for supporting horizontal needles	0 2 6 ..	0 10 0
A pair of 12 in. Magnetic Needles on stands for illustrating to a class, or in the lecture-room, the influence of one Magnet on another	1 1 0	
Pouillet's Astatic Needle, composed of 2 steel needles precisely similar, and placed parallel, but one above the other, the poles being reversed, or placed in opposite directions; by this means the influence of the earth's Magnetism is nearly neutralized. On brass stand with steel centre, 5 in. 6 in. 7 in. 8 in.	0 7 6 ..	1 1 0
Dipping Needle, consisting of a 5-inch magnetic needle, mounted on centre, with brass arc, upon which the dip is shown	0 10 6 ..	1 10 0
Dipping Needle, with graduated brass ring	0 17 6 ..	1 10 0
Dipping Needle of best construction for observation . Fig. 305	10 10 0 ..	20 0 0
Pocket Compasses, in square mahogany box, with lever stop, fitted with floating card, or plain needle	0 4 0 ..	0 10 0
Pocket Compasses, in round brass boxes, with pull-off lids, lever stop, with either floating card or needle	0 5 0 ..	0 12 0

	£ s. d.		£ s. d.
Pocket Mining Compass, with sights, levels, and plumb, for taking the inclination and direction of strata . . Fig. 298	1 5 0		
Pocket Compasses, in the form of a watch, with leather case .	0 2 6	to	0 12 0
Very Small Compasses, to attach to a watch-chain, either in gilt, silver, gold, or enamel case	0 1 6	..	0 5 [illegible]
Boat Compasses, in turned wood box, with floating card . .	0 13 0	..	0 18 0
Boat Compass, in brass box, with Gymbal's floating card . . These are so arranged as to act freely in every position.	0 15 0	..	1 5 0

MARINER'S COMPASSES.

	£ s. d.		£ s. d.
Sea, or Steering Compass. The needle fixed to a floating card, on the face of which the points of the compass are marked. This is fixed in a bowl, which is hung in gymbals, fixed in a wooden box	1 5 0	..	4 4 0
Cabin, or Hanging Compass. In this, the floating card, with its magnetic needle, is mounted with its face downwards . .	2 2 0	..	3 3 0
Azimuth Compass, with sights for determining the angular distances of objects from the magnetic meridian . . Fig. 300	2 12 6	..	12 12 0
Military Compass, consisting of a circular brass box, magnetic needle, with floating card, and folding sights for determining horizontal angles	2 12 6		
Prismatic Surveying Compass, consisting of a circular brass box, floating magnetic card, graduated ring, and folding sights, furnished with a triangular prismatic lens, in leather case . .	4 14 6		
Tripod Stand, with ball and socket joint	1 15 0		
Water's Azimuth Compass, with floating card and folding sights. A very portable instrument	2 12 6		
Miners' Compass, in brass box, large engraved compass dial, best needle, and folding sights, in mahogany box	2 2 0	..	7 7 0
Best Miners' Compass, with sights, cross levels, telescope, and mahogany staff	5 5 0	..	18 18 0
Faraday's Apparatus for showing that a permanent current of Electricity may be produced by an ordinary magnet Fig. 261	2 2 0	..	3 3 0
Sturgeon's Magnetometer, for showing the influence a magnet has on different metals when in motion	1 15 0	..	2 10 0
Apparatus to exhibit the capacity of various metals for the development of Magnetism by rotation, and also to illustrate the magnetic properties of different metals by motion	3 3 0	..	6 6 0
Barlow's Apparatus to show the probable origin of the phenomena of terrestrial magnetism; it consists of a globe, round which is wound a quantity of insulated copper wire, by the aid of which a current of Electricity can be passed over it, and the various phenomena of terrestrial magnetism explained . . .	3 3 0	..	5 5 0

ELECTRO-MAGNETIC INSTRUMENTS.

	£ s. d.		£ s. d.
Oersted's Apparatus for showing the deflection of the magnetic needle by a copper wire transmitting an electric current above or below it		..	0 12 6
Superior form of the instruments . . . . Fig. 307			
Dr. Roget's Apparatus to illustrate the relative positions of the magnetic needle and electric current	0 3 6	..	0 5 0
Ampère's Apparatus for showing the action of a fixed magnet on a movable rectangular wire, transmitting an electric current Fig. 312	1 10 0	..	2 12 6

Item	£	s.	d.		£	s.	d.
Another form in which the rectangular wire is caused to rotate	1	10	0	to	2	2	0
Magnus's Apparatus for reversing electric currents . Fig. 313	0	12	0	..	0	15	0
De la Rive's Floating Battery, showing the directive property of an Electrified wire . . . . . . Figs. 315, 316	0	4	6	..	0	7	6
Ampère's Astatic Rectangular Wires, annulling the influence of the earth's Magnetism . . . . . . Fig. 314	0	7	6	...	0	12	0
Spiral Wire, illustrating in a simple manner the directive tendency of an electrified wire . . . . . Fig. 317	0	5	0	..	0	10	6
Apparatus showing the rotation of a horizontal wire by the influence of the earth's Magnetism . . . . Fig. 318	1	10	0	..	2	2	0
Ampère's Apparatus, showing that a rectangular wire arranged so as to be movable round a horizontal axis will, when traversed by a Voltaic current, place itself in the plane of the magnetic meridian . . . . Fig. 319	1	1	0				
Ampère's Apparatus, illustrating the mutual action of two parallel electric currents . . . . . . Figs. 320, 321	1	11	6				
Apparatus for illustrating the laws of angular currents Fig. 324	1	1	0				
Ditto . . . . Fig. 326	0	10	6				
Apparatus to show the rotation of a wire carrying a current by the action of another current . . . . . Fig. 328	1	1	0				
Apparatus showing the action of solenoids or wires bent into a cork-screw form . . . . Fig. 331	1	1	0				
Dr. Roget's Spiral Vibrating Wire . . . . Fig. 335	0	12	0		1	1	0
Dr. Roget's Vertical Coil Galvanometer . . Fig. 338	1	11	6				
Gold-leaf Galvanometer . . . . Fig. 339	1	5	0		1	15	0
Faraday's Apparatus to show the rotation of a magnet round an electrified wire . . . . Fig. 343	0	15	0				
Apparatus showing the converse experiment, viz., the rotation of an electrified wire round the pole of a magnet . Fig. 344	0	10	0		1	1	0
Combined Apparatus for showing both experiments. . .	1	11	6				
Watkins' Apparatus to show the revolution of the pole of a magnet about a vertical wire transmitting an electric current. The rotation is reversed by changing the direction of the current .	1	1	0				
The same Apparatus, but with two magnets, showing the opposite rotations at the same time . . . . . Fig. 345	1	11	6				
Apparatus to show the rotation of a magnet round its own axis Fig. 347	1	1	0		1	11	6
Apparatus to show the converse of the last experiment, viz., an electrified wire rotating round the pole of a magnet . .	0	15	0		1	1	0
Ampère's Apparatus for exhibiting the rotation of a cylindrical galvanic battery round the pole of a horse-shoe magnet . .	0	15	0				
Magnet mounted with two rotating batteries . Fig. 349	1	1	0				
Marsh's Apparatus for showing the vibrating tendencies of an electrified wire when under the influence of a magnet Fig. 350	0	7	6		0	10	6
Apparatus consisting of a Stella-formed wheel, exhibiting the vibrating motion converted into a continued rotatory movement .	0	12	0		1	1	0
Ditto, with two Stella-wheels, showing contrary rotations . .	0	15	0		1	5	0
Rotating metallic disk, acting similar to the above, and proving that the Stella-form is not necessary . . . Fig. 352	0	15	0		1	1	0
Faraday's Apparatus for showing the rotatory motion of a wire, transmitting an electric current round the pole of a magnet .	0	15	0		1	1	0
Faraday's Rotatory and Marsh's Vibratory Wire, in the same instrument	1	1	0				
Glass Tube, with copper wire coil, for magnetizing steel needles .	0	2	6		0	7	6
Mounted on Stand, with binding screw connections . . .	0	10	6	..	1	1	0

ELECTRO-MAGNETS.

When a bar of soft iron is submitted to the influence of a Voltaic current, it acquires a very high degree of Magnetism, which it retains, so long as the current is continued; but on its ceasing, returns to its former state. If a bar of soft iron is, therefore, bent into the form of an ordinary horse-shoe magnet, and surrounded by a considerable coil of insulated copper wire—the two extremities being in connection with even a single pair of galvanic plates—the iron becomes a powerful magnet; and if made of sufficient size, and more battery power employed, will support many hundredweights . . . . 0 3 6 to 2

Mounted on Wood Stand, with scale pan of a form and construction suited to their power . . . . 2 2 0 .. 6

Electro-Magnets, on the plans of Roberts, Radford, and Jenks, as described in Noad's Manual, p. 670, made to order.

Ritchie's Apparatus to exhibit the rotation of a straight bar electro-magnet, under the influence of a magnet, by rapidly reversing the current, so that attraction is changed to repulsion Fig. 359 0 8 6 .. 0

Improved arrangement, superseding the use of mercury Fig. 361 0 12 0 .. 1

Ritchie's Vertical arrangement of the rotatory electro-magnet . 1 1 0

Ritchie's Apparatus, consisting of a cylindrical horse-shoe magnet, mounted on an adjusting tripod stand, with a pair of movable mercury flood cups, a pair of wire frames, a pair of wire coils; and also a Ritchie's rotatory magnet—the whole forming a very useful instrument for illustrating electro-magnetic laws Fig. 363 2 2 0

WORKING MODELS OF ELECTRO-MAGNETIC ENGINES,

On various plans, showing the application of Electro-Magnetism as a motive power.

Electro-Magnetic Motive Engine, consisting of two electro-magnets, with soft iron keepers, to which are attached two iron rods, connected with a crank, giving motion to a fly-wheel by means of a make and break connection 6 6 0

Bain's Electro-Magnetic Motive Engine.—This is fully described, p. 681, Noad's Manual . . . . . Fig. 363 6 6 0 .. 12 12 0

Electro-Magnetic Motive Model, in which the permanent magnets are fixed in a circular form, in the centre of which the electro-magnets revolve. The battery connection and the make and break being very conveniently arranged . . . . . . 5 5 0 .. 21 0 0

Electro-Magnetic Motive Engine, in which a series of permanent magnets are arranged on the periphery of a revolving wheel. The action of this machine is very perfect, and is readily applied to give motion to small models, as pumps, &c. . . . 12 12 0

Electro-Magnetic Motive Model, consisting of four vertical bar-magnets, and horizontal electro-magnets attached to a spindle, to which is fixed a contrivance for making and reversing the direction of the current, and producing rotatory motion . . 10 10 0

Electro-Magnetic Pendulum.—The vibrations being kept up by two electro-magnets, the alternate attractions in each being caused by the making and breaking contact through the medium of the oscillations . . . . 5 5 0 .. 8 8 0

	£ s. d.	£ s. d.
Electro-Magnetic Verge, consisting of a horizontal spring balance and pallet; by means of a small electro-magnet vibrations are produced as in the balance-wheel of a watch	1 11 6	to 2 12 6
Model of a small Circular Saw, which is set in motion by a Ritchie's revolving electro-magnet	3 3 0	
Model of a small Water Pump, set in motion by Electro-Magnetism	3 3 0	
Gamut of Bells, mounted on a mahogany stand, motion being given to the clapper by means of a revolving Ritchie's magnet	2 12 6	
Electro-Magnetic Motive Engines of any of the described forms, made to order.		
Hearder's Magnetometer as described in Noad's Manual, p. 684 Fig. 364		

ELECTRO-DYNAMIC APPARATUS.

	£ s. d.	£ s. d.
Simple apparatus for obtaining a spark from an ordinary horse-shoe magnet . . . Fig. 373	0 5 0	
Ritchie's Arrangement for showing the magnetic spark as obtained from an electro-magnet and detonating a mixture of oxygen and hydrogen gas . . . Fig. 371	1 11 6	.. 3 3 0
The same arrangement with permanent magnet	2 2 0	.. 5 5 0
Magneto-Electric Machine with the latest improvements, consisting of a compound magnet mounted on a mahogany stand, multiplying wheel and spindle, to which are attached the armatures; one (the quantity) being covered with insulated copper wire, the other (the intensity) with a much larger quantity of very fine insulated wire; by this instrument all the important phenomena of Electro-Magnetism are exemplified. The figures exhibit the method of arrangement . . . Fig. 372		
Soft iron, rendered magnetic . . . Fig. 373		
The heating effects . . . Fig. 374		
The production of light . . . Fig. 375		
The combustion of iron . . . Fig. 376		
The decomposition of water . . . Fig. 377		
The physiological effects, or the astonishing action on the muscles Fig. 378	10 10 0	..21 0 0
Smaller Machines for medical purposes, possessing the great advantage of being always ready, and dispensing with the battery required in the ordinary medical machines; with conductors for applying the magnetic fluid to the various parts of the body; tin case complete	5 5 0	..10 10 0
Magneto-Electric Machines, fitted up for the purpose of electro-plating and gilding		
The American Magneto-Electric Machine, consisting of a horse-shoe magnet, with a revolving armature, the whole enclosed in a small box, 10 inches long by 4½ inches square; this is a most compact instrument, and an excellent medium for the application of electricity medically	2 10 0	
Dr. Henry's Ribbon Coils for increasing the power of small batteries, and showing the effects of induced currents . Fig. 379	0 7 6	.. 1 1 0
Ditto ditto . . . Fig. 380		
Ditto ditto . . . Fig. 381		
Matteucci's Arrangement for showing the development of secondary or induced currents by the discharge of a Leyden jar or battery Fig. 383		

	£ s. d.	£ s. d.
Dr. Golding Bird's Apparatus for rapidly making, breaking, and reversing battery currents . . . . Fig. 384	0 15 0	
Callan's Electro-Magnetic Coils of stout and thin insulated wire, for experiments with induced currents	1 1 0 to	5 5
Electro-Magnetic Coil Machine, in which the battery contact is made and broken by a self-acting rotatory magnet. This is a very pretty and elegant apparatus . . . Fig. 386	1 11 6 ..	2 12 6
Dr. Bachhoffner's Arrangement of the Electro-Magnetic Coil. This is provided with a multiplying wheel-spring and latchet, by which the contact is made and broken with the battery with great rapidity	4 14 6	
Another form of the Coil Machine possessing the advantage of requiring no mercury, at the same time that it is self-acting Fig. 387		1 11 6
Rev. F. Lockey's Electro-Magnetic Coil Machine . Fig. 388		
Rev. F. Lockey's Scintillating Circle . . Fig. 389		
Rev. F. Lockey's Water Regulator. A very convenient contrivance for modifying the effects of the galvanic shock . Fig. 390	0 10 6	1 1 0
Henley's very powerful Electro-Magnetic Coil Machines Fig. 391		
Ruhmkorff's Induction Coil or Apparatus—		
Small size without condenser	7 7	
Large size with condenser . . Figs. 395, 396, 397	10 10	
Egg-shaped Glass with stop-cock and sliding-wire on post for experiments with the coil . . . . . Fig. 403		
Hearder's Improved Induction Coil	10 0 0 .	30 0 0
Bentley's Improved Induction Coil, with detached condenser .		
Hearder's Improved Induction Coil		

ELECTRIC TELEGRAPH APPARATUS AND INSTRUMENTS.

	£ s. d.
Simple Apparatus, to illustrate Cooke and Wheatstone's Electro-Magnetic Telegraph, as now in use	1 1 0
A pair of small Single Needle Instruments, illustrating the action of the Electro-magnetic Telegraph, either to a glass, or they may be used for conveying messages from one apartment to another, with small battery attached to each instrument . . .	5 5 0
Working Model to illustrate Wheatstone's Letter Electro-Magnetic Telegraph. It consists of a circular dial, the letters of the alphabet being painted round the edge with a revolving hand or pointer, which is moved by means of an escapement and Electro-Magnet attached to the back. The communicator, which may be placed in another apartment, consists of a disk, with similar letters, which are brought into connexion with an index, by means of radial pins making, at the same time, communication to the telegraph instrument through the connecting wires of the battery	
Six-inch Dial Instrument Communicator and Small Battery .	5 5 0
Twelve-inch Dial ditto	8 18 6
Another form of Wheatstone's Letter Telegraph, the communicator and dial being on the same board with a warning bell and pair of instruments	7 7 0
Single Needle Telegraph Instrument, in mahogany case, as shown Fig. 415	6 16 6
Double Needle Instrument . . . . Fig. 419	12 12 0

	£ s. d.	£ s. d.
Model, to illustrate the principle of Morse's Printing Telegraph .		
Morse's Printing Telegraph. By this instrument the messages are impressed on a paper band. The instrument complete . .	25 0 0 to	30 0 0
Model to illustrate the principle of Henley's Magneto-Electric Telegraph		
Henley's Single Needle Telegraph Instrument, complete . .	12 0 0	
Henley's best Double Needle Instrument	21 0 0	
Froment's Alphabet Telegraph		

ELECTRO-MAGNETIC BELLS.

	£ s. d.	£ s. d.
Small Warning Bell, with Clockwork and Electro-Magnet . .	2 2 0	
Larger ditto, in case	3 3 0 ..	5 5 0
Electro-Magnetic Bells, without Clockwork, caused to ring by the direct action of the battery	1 11 6 ..	3 3 0
C. V. Walker's Telegraph Bell, without Clockwork . . .	5 5 0	
C. V. Walker's Lightning Conductors	0 12 6 ..	0 15 0
Insulators of glass or earthenware, with iron bolts, nuts, and washers . . . . from	0 1 0	
Portable Galvanometers, for testing the telegraphic instruments and wires	3 3 0 ..	6 0 0
Copper wire, insulated with gutta percha . . per yard	0 0 4½ ..	0 0 9
Sand Batteries for Telegraph Purposes, in gutta percha troughs of twelve cells	1 12 0	
Model, to illustrate Wheatstone's Electro-Magnetic Clock. By this contrivance, the time of one standard clock is instantaneously communicated to any number of dials	2 12 6 ..	4 4 0
Bain's Electro-Magnetic Clocks . . . . . from	10 10 0	
Sheppard's Electro-Magnetic Clocks		